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SECOND COLLEGE ON MICROPROCESSORS: TECHNOLOGY AND APPLICATIONS IN PHYSICS

(18 April - 13 May 1983)

MICROPROCESSOR APPLICATIONS IN PROCESS CONTROL

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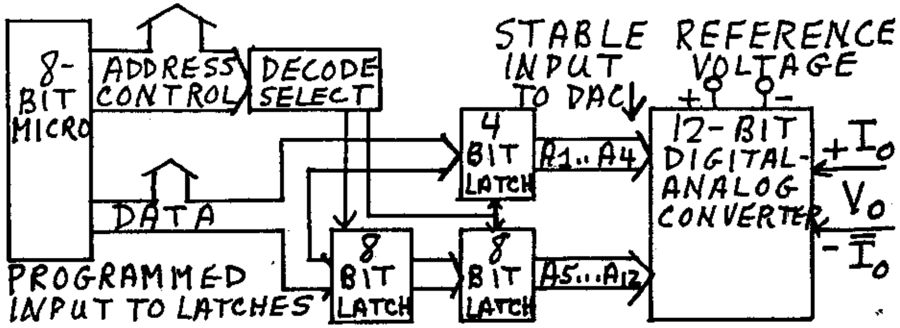
MICROPROCESSOR APPLICATIONS: DAC/ADC

DIGITAL-TO-ANALOG SCHEME-12 BIT EXAMPLE



OUTPUT: VOLTAGE (V_0) OR CURRENT (I_0)

$$V_0 = K \cdot V_{FS}[A_1 * 2^{-1} + A_2 * 2^{-2} + \cdots + A_N * 2^{-N}] + V_{OS}$$

K= GAIN (USUALLY ADJUSTED TO VALUE OF ONE)

V_{FS}= FULL-SCALE OUTPUT VOLTAGE

$A_1\ A_2 \ldots A_N$= N-BIT INPUT WORD (BINARY OR BCD)

V_{OS}=OFFSET VOLTAGE (=V_0 FOR $A_1 = A_2 = \ldots = A_N = 0$)

V_{REF} CONTROLS OUTPUT VOLTAGE OR CURRENT

$V_{FS} \approx V_{REF}$; TYPICAL $I_{FS} \approx 2.0$ MILLIAMP.

RESOLUTION=SMALLEST CHANGE IN V_0 ($V_{FS}/2^N$)

FOR 12 BIT: 1 PART IN 4096 OR ≈ 0.025 PERCENT

TYPICAL V_{FS}: 2.5, 5.0, 10.0, 5.12, 10.24 VOLTS

V_0 MAXIMUM IS ONE LSB LESS THAN V_{FS}

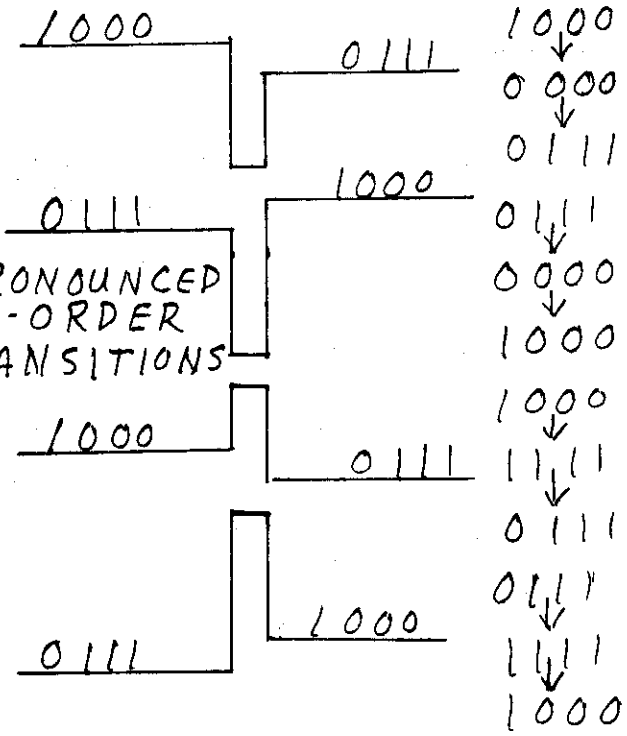
REAL DAC CAN HAVE ERRORS IN LINEAR APPROXIMATION: GAIN (SLOPE) AND OFFSET (≠0)

ALSO NON-LINEAR BEHAVIOR

MICROPROCESSOR APPLICATIONS

GLITCHES IN DAC OUTPUTS

PASSING FROM OLD TO NEW INPUTS

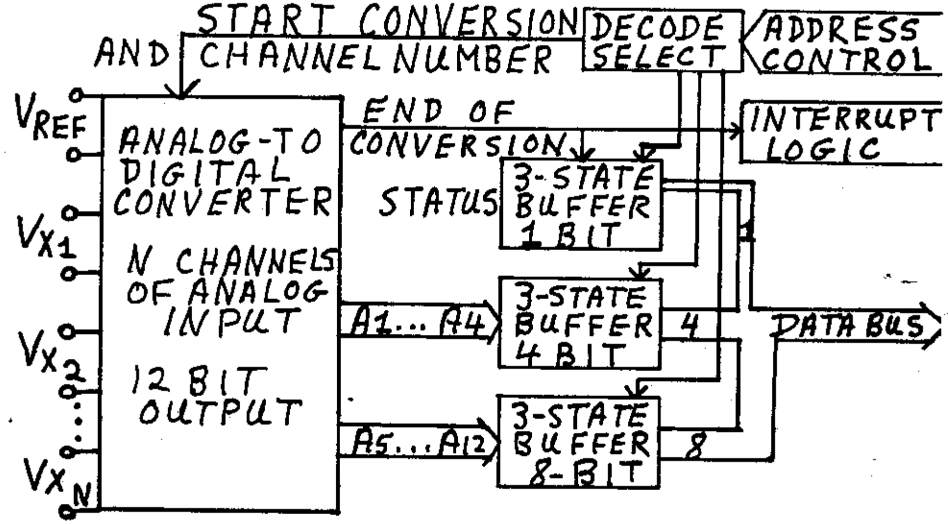


MOST PRONOUNCED AT HIGH-ORDER BIT TRANSITIONS

GLITCHES CAN ARISE IF TURN-OFF TIME DIFFERENT FROM TURN-ON TIME OR IF INPUT DATA SKEWED IN ARRIVAL

MICROPROCESSOR APPLICATIONS: DAC/ADC

ANALOG TO DIGITAL SCHEME: 12 BIT EXAMPLE



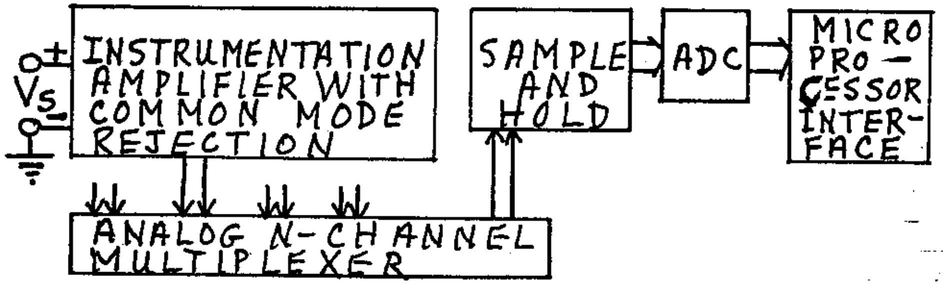
RECENT CONVERTER ANNOUNCEMENTS INCLUDE CIRCUITRY FOR: ADDRESS DECODING AND THREE-STATE BUFFERING

VOLTAGE REFERENCE OFTEN SUPPLIED INTERNALLY

CONVERSION TIME OFTEN >> μ-PROC INSTRUCTION

THUS FORESEE STATUS CHECKING OR INTERRUPT OR BOTH

FULL CHAIN OF ELEMENTS IN ADC SYSTEM



MICROPROCESSOR APPLICATIONS

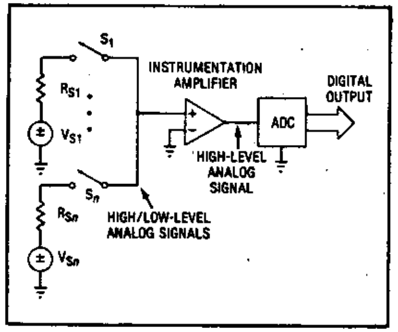


Figure 1. Common analog input system with low-level multiplexer.

COMMON ANALOG INPUT SYSTEM WITH LOW-LEVEL ANALOG MULTIPLEXER- VERY SENSITIVE TO NOISE PROBLEMS

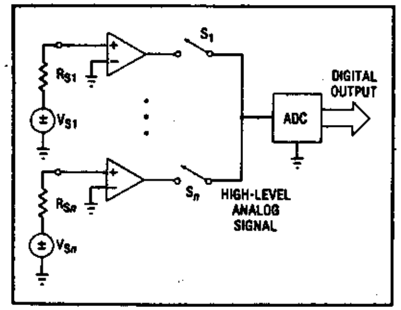


Figure 2. Amplifier-per-channel analog input system.

AMPLIFIER PER ANALOG CHANNEL SWITCHES ONLY HIGH LEVEL ANALOG SIGNAL IN ANALOG MULTIPLEXER.

BETTER

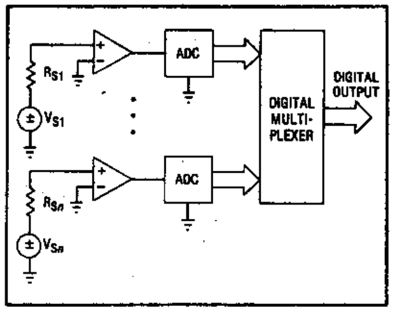


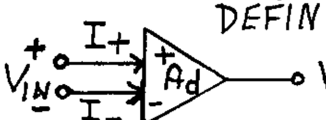
Figure 3. Analog input system with an amplifier *plus* an ADC on every channel—no analog multiplexing is required.

BEST ANALOG INPUT SYSTEM WITH AMPLIFIER AND ADC FOR EACH CHANNEL. THERE IS NO ERROR IN DIGITAL TYPE MULTIPLEXER

TECHNOLOGICAL PROGRESS CONTINUALLY MAKES BEST SOLUTION MORE ECONOMICAL.

OPERATIONAL AMPLIFIER (OP-AMP) CIRCUITS

OP AMP = HIGH GAIN DIFFERENTIAL AMPLIFIERS
USED TO PERFORM AN OPERATION
SUCH AS SUMMING, INTEGRATION, SCALING
DEFINED BY FEEDBACK NETWORK



$V_{OUT} = A_d \cdot V_{IN}$

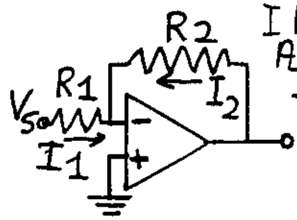
$\underbrace{\text{IDEALIZATIONS}}$
INFINITE INPUT IMPEDANCE
INFINITE GAIN

BASIC OP AMP: $I_+ \to 0 \leftarrow I_-$

$V_{IN} = \frac{V_{OUT}}{A_d} \to 0$ AS $A_d \to \infty$

FOR FINITE OUTPUT VOLTAGE, V_{IN} IS INFINITESIMAL
FOR SIMPLIFIED CIRCUIT ANALYSIS, ASSUME
1. ZERO INPUT CURRENT TO AMPLIFIER
2. ZERO INPUT VOLTAGE TO AMPLIFIER

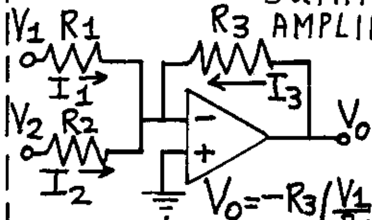
INVERTING AMPLIFIER



$I_1 = -I_2$

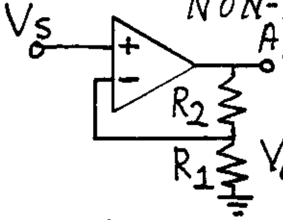
$V_0 = -\frac{R_2}{R_1} V_S$

SUMMING AMPLIFIER



$V_0 = -R_3\left(\frac{V_1}{R_1} + \frac{V_2}{R_2}\right)$

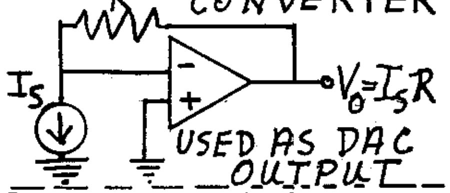
NON-INVERTING AMPLIFIER



$V_0 \frac{R_1}{(R_1+R_2)} = V_S$

$V_0 = V_S\left(1 + \frac{R_2}{R_1}\right)$

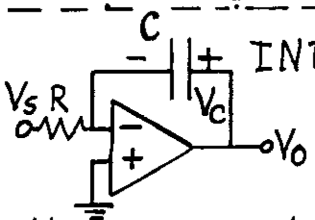
CURRENT-TO-VOLTAGE CONVERTER



$V_0 = I_S R$

USED AS DAC OUTPUT

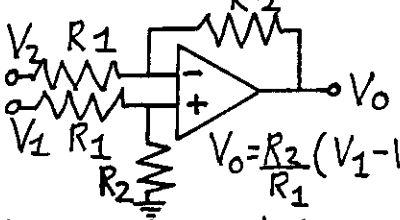
INTEGRATOR



$\frac{V_S}{R} = -\frac{dQ}{dt} = -C\frac{dV}{dt}$

$V_0 = -\frac{1}{RC}\int_0^t V_S\,dt + V_c(0)$

DIFFERENTIAL AMPLIFIER



$V_0 = \frac{R_2}{R_1}(V_1 - V_2)$

$\frac{V_2 - V_{IN}}{R_1} = -\frac{(V_0 - V_{IN})}{R_2}$; $V_{IN} = \frac{R_2 V_1}{(R_1+R_2)}$

MICROPROCESSOR APPLICATIONS ADC/DAC

THERMOCOUPLE (IRON-CONSTANTAN) HAS
OUTPUT VOLTAGE: 0°C → 0.000 VOLTS
500°C → 27.4 MILLIVOLTS

$\frac{\Delta V}{\Delta T} \approx \frac{27.4\ MV}{500\ DEG} \lesssim 55$ MICROVOLTS/DEGREE CELSIUS

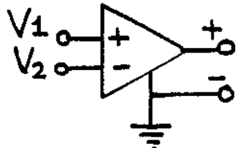
0.1 DEGREE RESOLUTION ⇒ 5 μVOLT SENSITIVITY

12 BIT ADC WITH $V_{FS} = 10.24$ HAS $\frac{10.24}{4096} = 2.5MV$ "

THUS NEED AMPLIFIER WITH GAIN ≈ 500.

USE PRECISION INSTRUMENTATION AMPLIFIER
MADE WITH THREE OP-AMPS AS FOLLOWS

FIRST EXAMINE OFFSET VOLTAGE V_{OS} AND
COMMON MODE REJECTION OF DIFFERENTIAL AMP



SHOULD AMPLIFY $(V_1 - V_2)$ AND
REJECT COMMON SIGNAL $\frac{(V_1+V_2)}{2}$

ACTUALLY; $V_0 = A_D(V_{OS} + \lambda V_{CM} + V_{DM})$

$V_{DM} = V_1 - V_2$ = DIFFERENTIAL MODE INPUT

$V_{CM} = (V_1 + V_2)/2$ = COMMON MODE INPUT

A_D = DIFFERENTIAL MODE GAIN

V_{OS} = EQUIVALENT INPUT OFFSET VOLTAGE

λ = COMMON MODE REJECTION RATIO

FOR V_{OS}, LET $V_{DM} = 0 = V_{CM}$, FOR ZERO INPUT

$V_{OUTPUT} = V_{OO} \neq 0$, EQUIVALENT $V_{OS} \approx \frac{V_{OO}}{A_D}$

$V_{OS} \approx$ FEW (1-3) MILLIVOLTS

MICROPROCESSOR APPLICATIONS ADC/DAC

DIFFERENTIAL AND INSTRUMENTATION AMPS

CMRR: IF $V_{CM} \neq 0$, V_{OS} CHANGES $\propto V_{CM}$

$V_O = A_D(\lambda V_{CM}) = (A_D \lambda) V_{CM} = A_C V_{CM}$

λV_{CM} = EQUIVALENT INPUT TO PRODUCE V_O

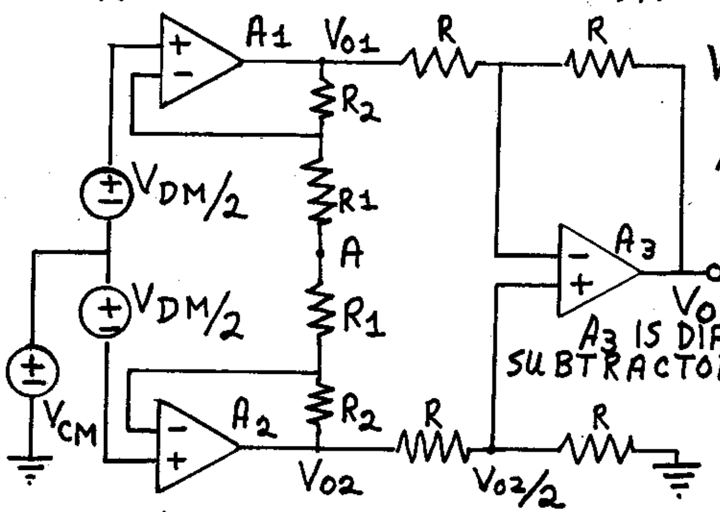
A_C = COMMON MODE GAIN

$\lambda = A_C / A_D$ IS OFTEN USED TO SPECIFY CMRR

TYPICALLY CMR $= -20 \log_{10} \lambda$ IN DECIBELS ($\sim$80)

CMR = 80 $\Rightarrow \lambda = 0.0001$ WHICH MEANS THAT

V_{CM} = 10 VOLTS SIMULATES V_{DM} = 0.001 VOLT



$V_{O\frac{1}{2}} = V_{CM} \pm \left(1+\frac{R_2}{R_1}\right)\frac{V_{DM}}{2}$

A = VIRTUAL GROUND BY SYMMETRY FOR V_{DM} SIGNALS

A_3 IS DIFFERENTIAL SUBTRACTOR WITH GAIN = 1

AT A_3; $\left(V_{O1} - \frac{V_{O2}}{2}\right)\frac{1}{R} = \frac{-1}{R}\left(V_O - \frac{V_{O2}}{2}\right)$; $V_O = V_{O2} - V_{O1}$

$V_O = -\left(1+\frac{R_2}{R_1}\right) V_{DM}$ WITH COMMON MODE SUBTRACTED

CMR $\approx \Delta = \underbrace{\lambda_1}_{\text{INPUT}} + \underbrace{\lambda_2/A_D}_{\text{SUBTRACTOR}}$; $\lambda_2 \approx 2\frac{\Delta R}{R}$; $A_D = 1 + R_2/R_1$

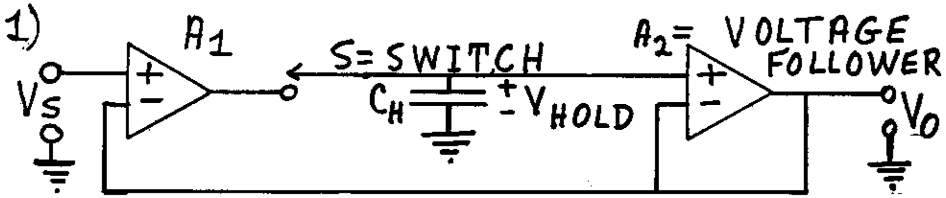
$\frac{\Delta R}{R} \propto 0.01\%$

MICROPROCESSOR APPLICATIONS: DAC/ADC

SAMPLE-AND-HOLD CIRCUIT CAPTURES INPUT ANALOG SIGNAL AND THEN HOLDS IT CONSTANT DURING ADC SEQUENCE

USE TWO OP-AMPS IN ONE OF TWO WAYS

1)



SAMPLE: S CLOSED; $V_O = V_S = V_H$

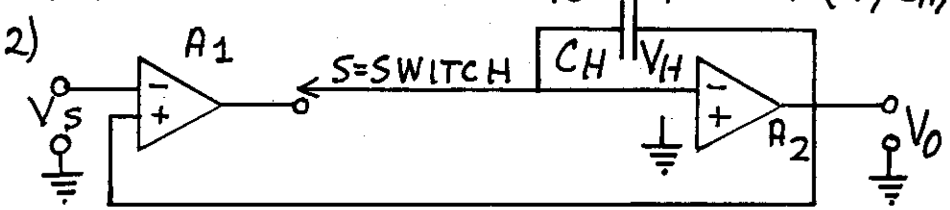
HOLD: S OPEN; V_S (STORED ON C_H) $= V_H = V_O$

REALLY TRACK-AND-HOLD SINCE $V_O = V_S$ (S CLOSED)

DROOPING: SMALL INPUT BIAS CURRENT OF A_2 (NON-IDEAL) CHARGES OR DISCHARGES C_H

DROOP RATE: 0.001 – 5 VOLTS/SEC = F(T, C_H)

2)

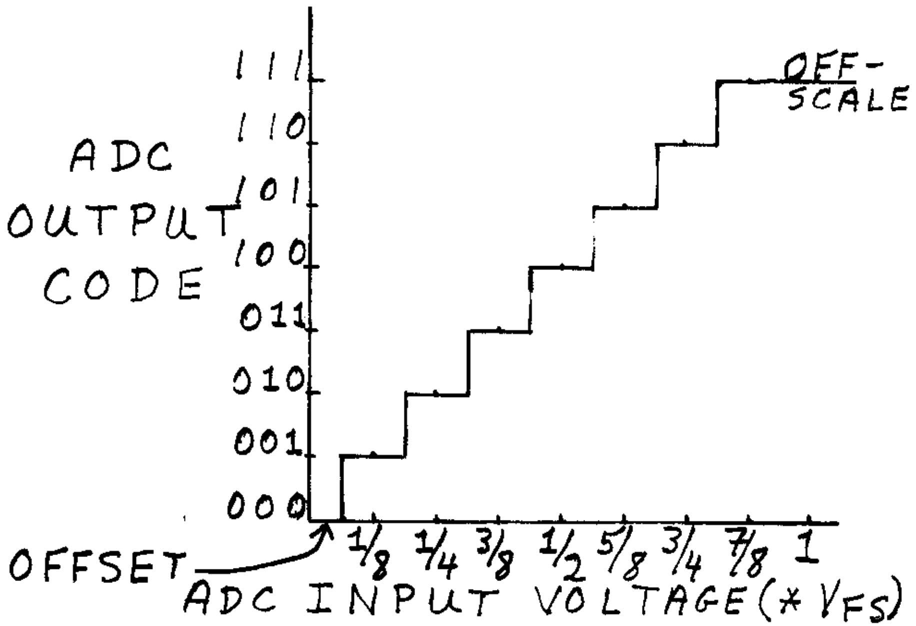


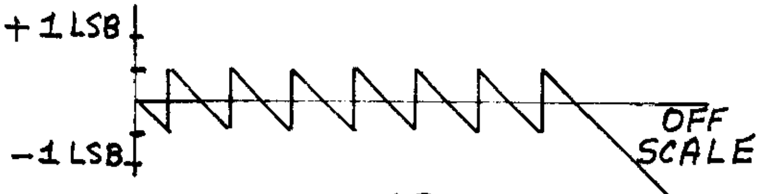
SAMPLE: S CLOSED; $V_O = V_S = V_H$ SINCE INVERTING INPUT TO A_2 IS A VIRTUAL GROUND

HOLD: S OPEN, $V_O = V_H$; CHARGING CIRCUIT OPEN

MICROPROCESSOR APPLICATIONS

INPUT-OUTPUT RELATIONSHIP FOR IDEAL THREE-BIT ADC





QUANTIZATION ERROR FOR IDEAL THREE-BIT ADC (MINIMIZED BY OFFSET AT ORIGIN)

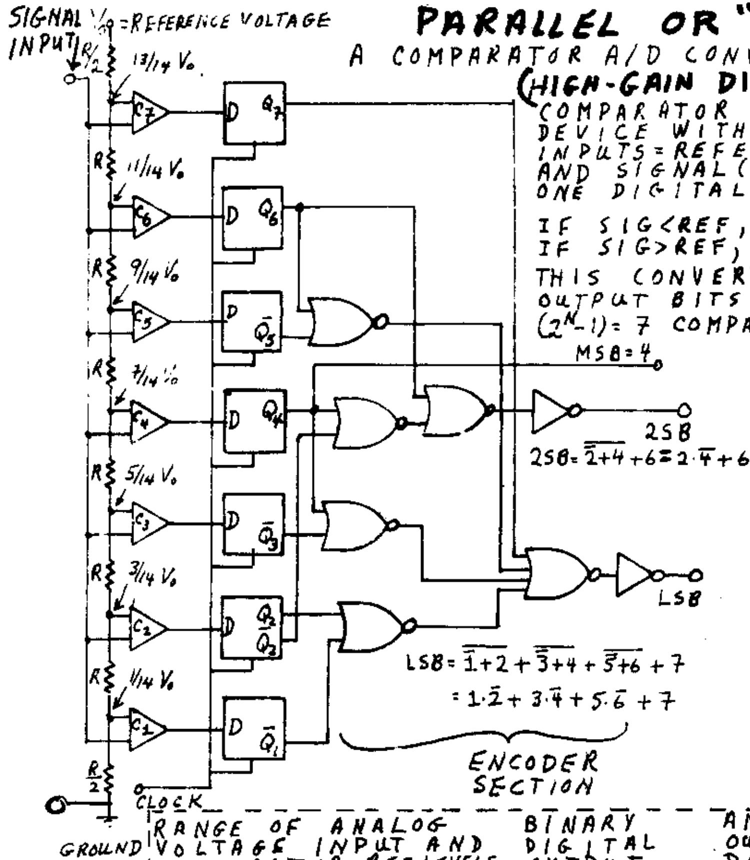
PARALLEL OR "FLASH"

A COMPARATOR A/D CONVERTER (HIGH-GAIN DIFF-AMP)

COMPARATOR IS A HYBRID DEVICE WITH TWO ANALOG INPUTS = REFERENCE (REF) AND SIGNAL (SIG) AND ONE DIGITAL OUTPUT

IF SIG<REF, OUTPUT = 0
IF SIG>REF, OUTPUT = 1

THIS CONVERTER WITH N=3 OUTPUT BITS REQUIRES $(2^N-1) = 7$ COMPARATORS.



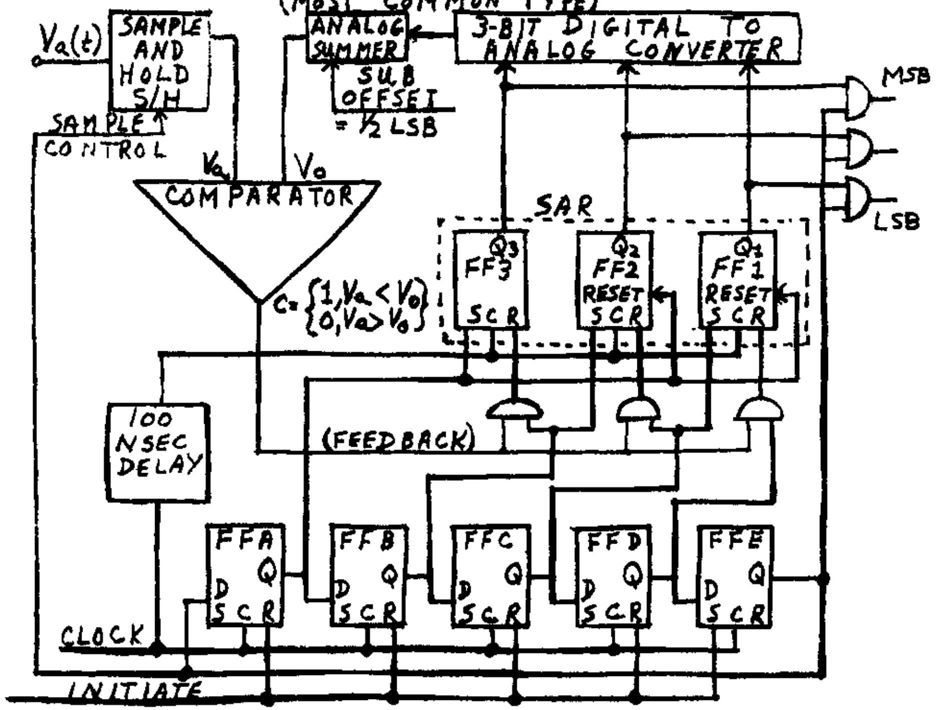
$2SB = \overline{\overline{2}+4+6} = 2\cdot\overline{4}+6$

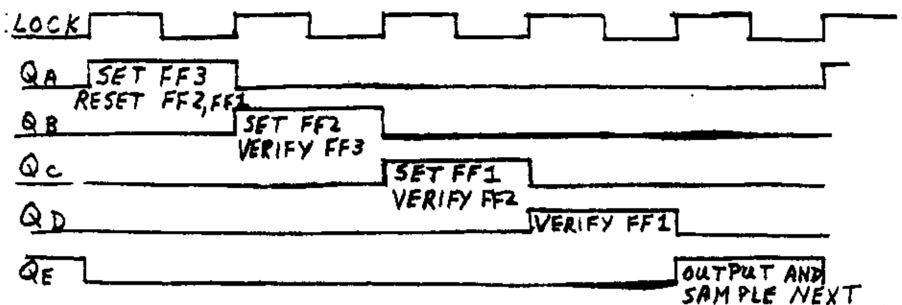
$LSB = \overline{\overline{1}+2}+\overline{\overline{3}+4}+\overline{\overline{5}+6}+7$
$= 1\cdot\overline{2}+3\cdot\overline{4}+5\cdot\overline{6}+7$

RANGE OF ANALOG VOLTAGE INPUT AND COMPARATOR REF LEVELS	BINARY DIGITAL OUTPUT	ANALOG VOLTAGE OUTPUT FROM D/A CONVERTER
V_0		
$V_{R7} = 13/14\ V_0$	111	V_0
$V_{R6} = 11/14\ V_0$	110	$6/7\ V_0$
$V_{R5} = 9/14\ V_0$	101	$5/7\ V_0$
$V_{R4} = 7/14\ V_0$	100	$4/7\ V_0$
$V_{R3} = 5/14\ V_0$	011	$3/7\ V_0$
$V_{R2} = 3/14\ V_0$	010	$2/7\ V_0$
$V_{R1} = 1/14\ V_0$ (S, S/2)	001	$1/7\ V_0$
0	000	0

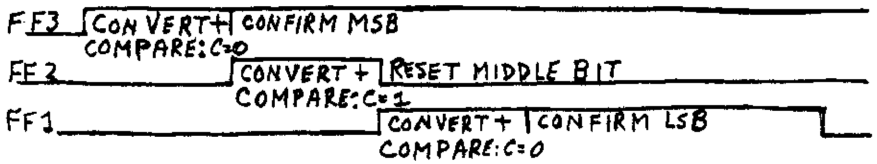
UNIPOLAR ANALOG VOLTAGE IS DIVIDED INTO INTERVALS AND INTERVALS ASSIGNED DIGITAL VALUES IN MANNER ASSURING UNIFORM MAX QUANTIZATION ERROR OVER ENTIRE RANGE

3-BIT 5-CYCLE SUCCESSIVE APPROXIMATION ADC
(MOST COMMON TYPE)

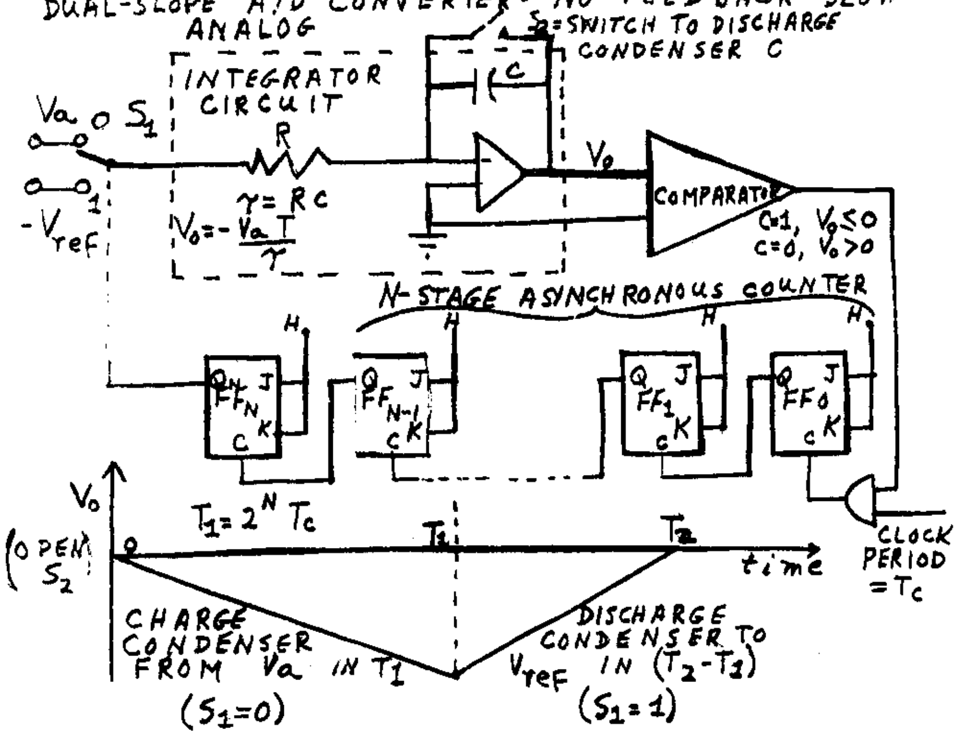




SAR= SUCCESSIVE APPROXIMATION REGISTER FOR ADC=5



DUAL-SLOPE A/D CONVERTER - NO FEEDBACK - SLOW



OPERATION:

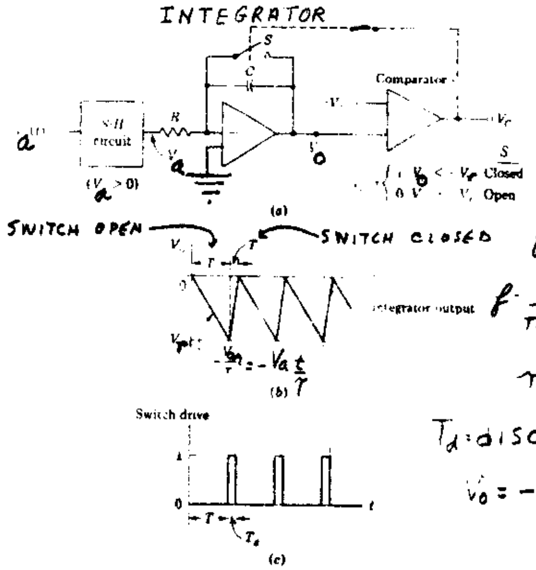
at $t=0$, OPEN S_2, RESET COUNTER, $Q_N = 0 \Rightarrow S_1$ = SAMPLE V_a
COUNTER COUNTS UP FROM ZERO

at $t = 2^N$ CLOCK PERIODS $= 2^N T_c$, $Q_N \to 1$ COMMUTES S_1 TO V_{ref}
CONDENSER HAS CHARGE $= -\frac{V_a T_1}{\tau} = -\frac{V_a 2^N T_c}{\tau}$

at $t = T_2$, C=0 = STOP COUNT BECAUSE CONDENSER POSITIVE AND $V_o > 0$. COUNT $= K < 2^N$.

RELATION: |CHARGE| = |DISCHARGE|, $\frac{V_a 2^N T_c}{\tau} = \frac{V_{ref} K T_c}{\tau}$

OR $V_a = \frac{K}{2^N} V_{ref}$, PROPORTIONAL TO N-BIT COUNT.



V_A = V reference

T: INTEGRATION TIME

f: frequency

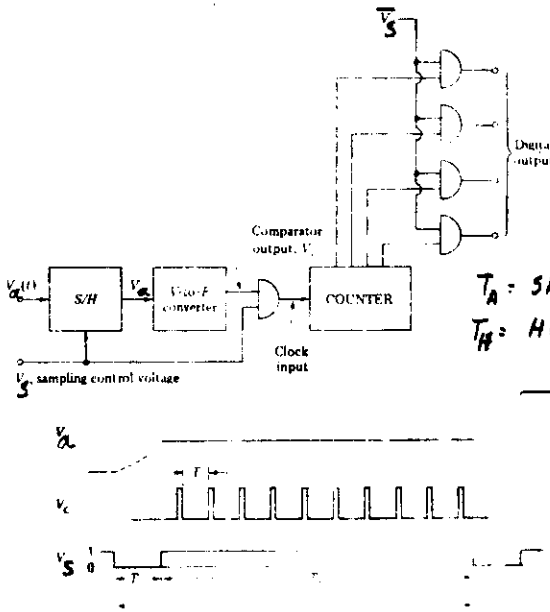
$$f = \frac{1}{T+T_d} \approx \frac{1}{T} = \frac{1}{\tau}\left(\frac{V_{analog}}{V_{reference}}\right)$$

τ = RC: TIME CONSTANT

T_d: discharge time

$$V_o = -V_a \frac{t}{\tau} \approx V_r \text{ for } t = T$$

FIGURE 14.17-1
(a) A V/F converter (b) The waveform V_o (c) The waveform which drives the SWITCH



T_A: SAMPLING PERIOD

T_H: HOLD PERIOD

MICROPROCESSOR APPLICATIONS: DAC/ADC

ADC COMPARISON

TYPE	TYPICAL CONVERSION RATE (/SEC)	COST OR COMPLEXITY	COMMENTS
COUNTER-RAMP	LOW AND VARIABLE ≤ 1000/SEC	LOW	
SINGLE-RAMP	LOW AND VARIABLE ≤ 1000/SEC	LOW	LACK LONG-TERM STABILITY
DUAL-RAMP	LOW AND VARIABLE ≤ 1000/SEC	MEDIUM	INTEGRATES INPUT SIGNAL HIGH RESOLUTION ≤ 20 BITS
SUCCESSIVE APPROXIMATION	MEDIUM FIXED $\leq 10^6$	MEDIUM	NEEDS STABLE INPUT, MEDIUM RESOLUTION ≤ 12-16 BITS
PARALLEL (FLASH)	FASTEST FIXED $10^6 - 10^8$	HIGH	LOW RESOLUTION ≤ 6-8-16 BITS
V/F CONVERTER AND COUNTER	LOW FIXED ≤1000/SEC	LOW	LACK LONG-TERM STABILITY

REF: R.C. JAEGER, IEEE MICRO, MAY 1982 P20
AUG 1982 P46
NOV 1982 P20
FEB 1983 P52

TAUB + SCHILLING, DIGITAL INTEGRATED ELECTRONICS, MCGRAW-HILL 1977, CHAPTER 14

MICROPROCESSOR APPLICATIONS-ROBOTS

IN CZECHOSLOVAKIAN, "ROBOTA" MEANS SERVITUDE AND DRUDGERY; PORTRAYED BY HUMAN WORKERS IN 1920 PLAY BY CZECH PLAYWRIGHT KAREL CAPEK

ROBOTS PRECEDED IN TIME BY

A) TELEOPERATOR-DEVELOPED DURING WORLD WAR II FOR HANDLING RADIOACTIVE MATERIALS AT A "SAFE" DISTANCE.

1. LINK MECHANISMS FED BACK FORCE

1947-SERVO MECHANISMS (LACKED FORCE FEEDBACK)

1948 "FEELING" RESTORED BY "BACK-DRIVING" MASTER

-B. NUMERICAL CONTROL (NC) MILLING MACHINE

1953-COMBINED SOPHISTICATED SERVO SYSTEM AND DIGITAL COMPUTER TECHNIQUES (REPETITION BY RE-READING INPUT TAPE)

1960-FIRST INDUSTRIAL ROBOT COMBINED

1. ARTICULATED LINKAGE OF TELEOPERATOR

2. SERVOED AXIS OF NC MILLING MACHINE

"TAUGHT" TO PERFORM SIMPLE TASK BY HAND DRIVING THRU SEQUENCE RECORDED IN DIGITAL MEMORY

-NOW ALSO SOFTWARE PROGRAMMABLE

MICROPROCESSOR APPLICATIONS-ROBOTS

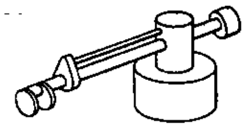
USES: CASTING/FORGING
SPRAY PAINTING
WELDING
LOADING AND UNLOADING
ASSEMBLING AND SORTING PARTS

POSITIONS: ON FLOOR
MOVING WITH PRODUCTION LINES
OVERHEAD HANGING DOWN
MOUNTED SIDEWAYS ON WALLS

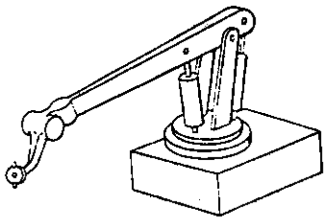
CAPABILITY: STRENGTH (HUNDREDS OF KG)
SIMPLE VISION (RESEARCH+COMPUTER)
TACTILE SENSING (RESEARCH)
LEARNING BY FOLLOWING
IMMUNITY TO ENVIRONMENTAL HAZARDS
RELOADABLE PROGRAM

DEFINITION
PROGRAMMABLE MANIPULATOR THAT CAN PERFORM USEFUL WORK AUTOMATICALLY WITHOUT HUMAN ASSISTANCE

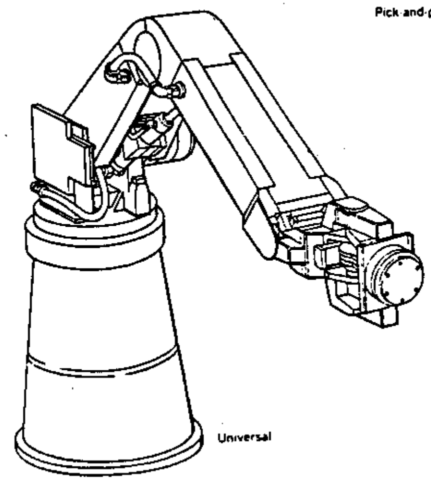
TYPES



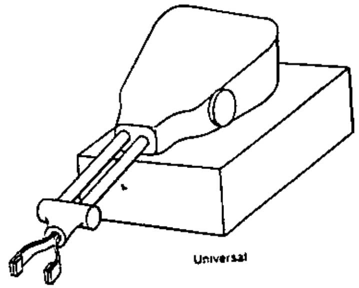
Pick-and-place



Special purpose



Universal



Universal

MICROPROCESSOR APPLICATIONS- ROBOTS

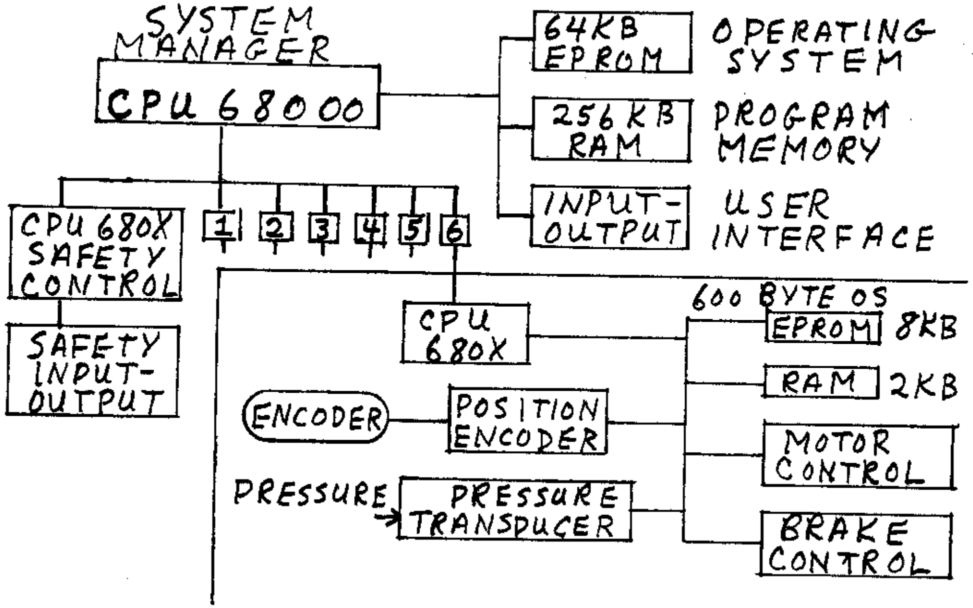
MULTI-MICROPROCESSOR ROBOT CONTROLLER BY L.A. GOSHORN, COMPUTER DESIGN, NOV 1982, P.193 TO CONTROL FIVE AXES PLUS GRIPPER. WITH AIR MOTORS WHICH COST ~1/10 DC SERVOMOTORS BUT REQUIRE MUCH COMPUTING POWER (2 MHz) TO CONTROL FOR DIFFERENT SPEEDS AND LOADS

CONFIGURATION: ALL ON 6-LAYER BOARD

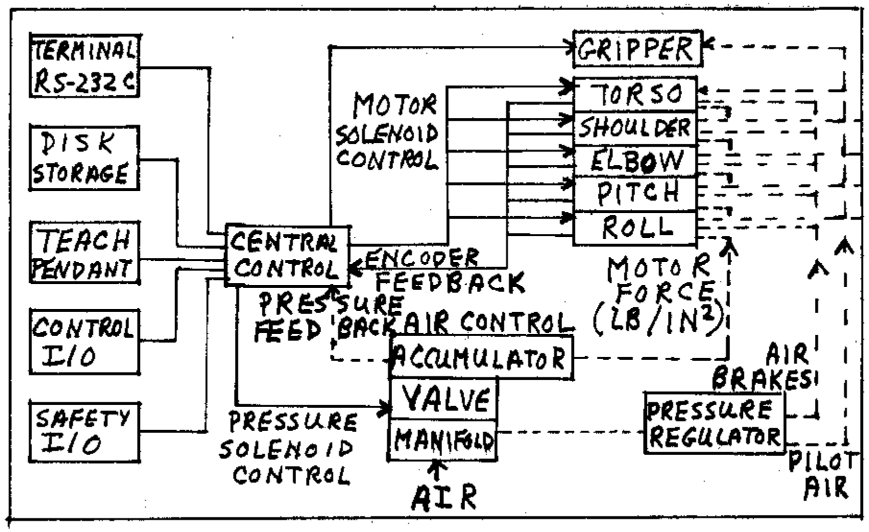
M68000-OVERSEES TOTAL ROBOT OPERATION PLUS ≤256KB RAM, 64KB EPROM

6-M680X (ONE FOR EACH OF 5 AXES, PLUS GRIPPER) PLUS 2KB RAM, 8KB EPROM EACH

1-M680X FOR SAFETY CONTROL AND SAFETY I/O



MICROPROCESSOR APPLICATIONS



ROBOT SYSTEM COMPONENT BLOCK DIAGRAM: CENTRAL CONTROL = MONOBOARD

ADVANTAGES OF SINGLE BOARD

1. CAN BE ONBOARD ROBOT ELIMINATING CABLING, CONNECTORS, OCCUPIED FLOOR SPACE OF SEPARATE CONTROL COMPUTER
2. FURTHER ELIMINATES COSTS OF CARD-CAGE BACKPLANE (MOTHERBOARD), INTERCONNECTS
3. PERMIT EASIER CONVECTION COOLING ON SHOCK-ISOLATED SWING-OUT CHASSIS

MICROPROCESSOR APPLICATION -ROBOT
COMMUNICATIONS BETWEEN PROCESSORS
AND EXTERNAL SIGNAL SOURCES

BUSES:
2 SERIAL COMMUNICATIONS BUSES
PENDANT DIRECT CONTROL BUS
POWER SUPPLY AND GROUND (2 LAYERS)
TRANSDUCER MONITOR (DIAGNOSTIC AND ANALOG)
COMPUTER EXPANSION BUS
MEMORY EXPANSION BUS
POSITION FEEDBACK BUS
INDUSTRIAL I/O BUS
MAINTENANCE MONITOR BUS

SPECIAL COMMUNICATION SCHEME BETWEEN MASTER AND EACH AXIS CONTROL COMPUTER
- USES MAILBOX = PAIR OF REGISTERS
- SEMAPHORE ASSOCIATED WITH EACH REGISTER
- BUFFER FULL CAUSES VECTORIZED (UNIQUE) INTERRUPT IN MASTER 68000, AND
- REGULAR INTERRUPT IN AXIS CONTROL
- MASTER CAN WRITE TO ANY COMBINATION OR ALL FOR SYNCHRONIZATION OR FOR EMERGENCY

MICROPROCESSOR APPLICATIONS- ROBOTS
ROBOT COMMANDS FOR RCL INTERPRETER

HOME- MOVE AXES TO HOME POSITIONS
INIT- CLEAR CONTROLLER + SET ROBOT TO POINT
MOVE- MOVE AXIS THRU ANGLE AT SPEED
OPEN- START OPENING GRIPPER + WAIT
CLOSE- START CLOSING GRIPPER + WAIT
TOL- SPECIFY POSITION TOLERANCE FACTOR
SPEED- SPECIFY SPEED FACTORS TO AXES
SMOD- MODIFY EQUALLY PRESENT SPEED FACTORS
COMPP- COMPUTE PRESSURE REFERENCE FOR EACH AXIS AS FUNCTION OF LOAD AND SPEED
PRES- TRANSMIT PRESSURE REFERENCE TO AXES
LOAD- SPECIFIES PAYLOAD BEING CARRIED BY ROBOT
DEBUGON- PRINTS STARTING, TARGET, AND ACTUAL ANGLE POSITIONS FOR EACH AXIS AFTER EXECUTING EACH MOVE
DEBUGOFF- STOPS DEBUGON FEATURE
AXIS- ENABLES(1)/DISABLES(0) AXIS COMMUNICATION
SNAP- ENABLES(1)/DISABLES(0) SNAPSHOT REQUESTS DURING VARIOUS MODES OF CONTROL (ACCELERATION, VELOCITY, DECELERATION).

ROBOT POINTS ARE ENTERED USING PENDANT = PORTABLE HAND HELD PROGRAMMER.

MICROPROCESSOR APPLICATIONS - ROBOTS

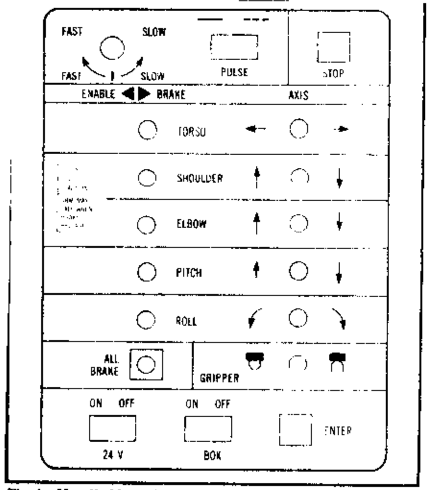


Fig 4 Handheld teach pendant programming aid. By manually controlling robot's motion with teach pendant, users can quickly and easily program robot for most pick and place tasks.

REF: COMPUTER DESIGN, NOV 1982 P 169 AND P 193

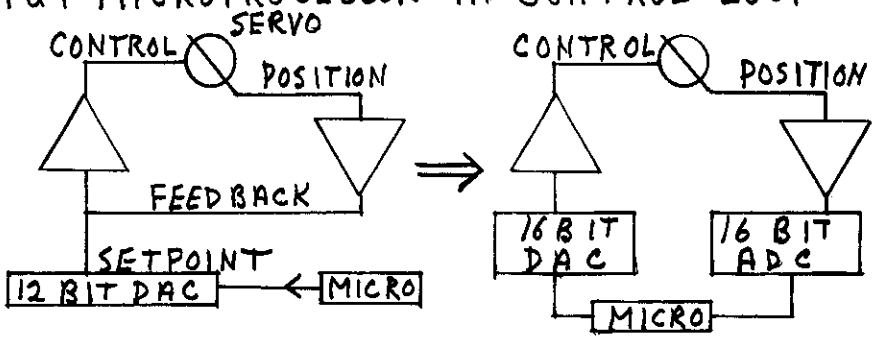
IEEE SPECTRUM, SEPT 1979 P 31

COMPUTER MAGAZINE (IEEE COMPUTER SOCIETY) JULY 1979, P 19

DEC, 1982 - ENTIRE ISSUE DEDICATED TO ROBOTICS + AUTOMATION

MICROPROCESSOR TRENDS USEFUL FOR ROBOTS

1. PUT MICROPROCESSOR IN CONTROL LOOP

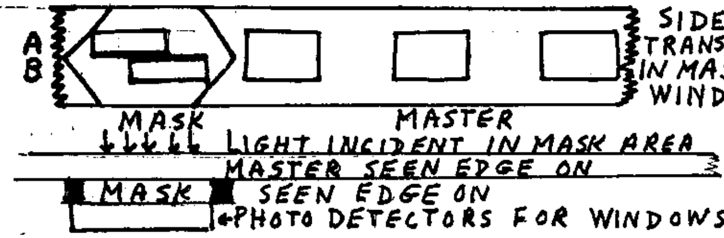


ALGORITHM CAN COMPENSATE FOR LOAD VARIATION, ROBOT DEFORMATION UNDER LOAD, TOLERANCE, ETC

2. DEDICATE PROCESSOR PER AXIS
3. GIVE MASTER PROCESSOR MORE THAN 64KB
4. TIGHTLY COUPLED PARALLEL MULTIPROCESSING
   FAST SHARING OF PARAMETERS IN REGISTERS (MEM)
5. MPY AND DIVIDE FOR COORDINATE CALCULATIONS
6. LOOSELY COUPLED HIGH-SPEED SERIAL LINKS - FOR PRODUCTION FLOOR COORDINATION
7. USART's WITH ADDRESS RECOGNITION CAPABILITY
   WAKE-UP PROCESSOR ONLY WHEN ADDRESS OF OWN STATION HAS BEEN RECOGNIZED
8. INCREASED INTEGRATION OF WELL-ESTABLISHED INTELLIGENT PERIPHERAL FUNCTIONS

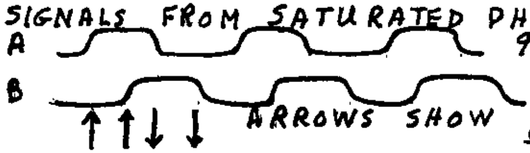
EXAMPLE: MOTOROLA 68200 SINGLE CHIP COMPUTER
INCLUDES: THREE 16-BIT TIMERS
USART 250 KBIT ASYNC, 1 MBIT SYNC
TWO 16-BIT PARALLEL I/O PORTS
INTERRUPT CONTROLLER
ON-CHIP DMA CONTROLLER
BUS ARBITRATION

DIRECT ANALOG-TO-DIGITAL POSITION CONVERSION



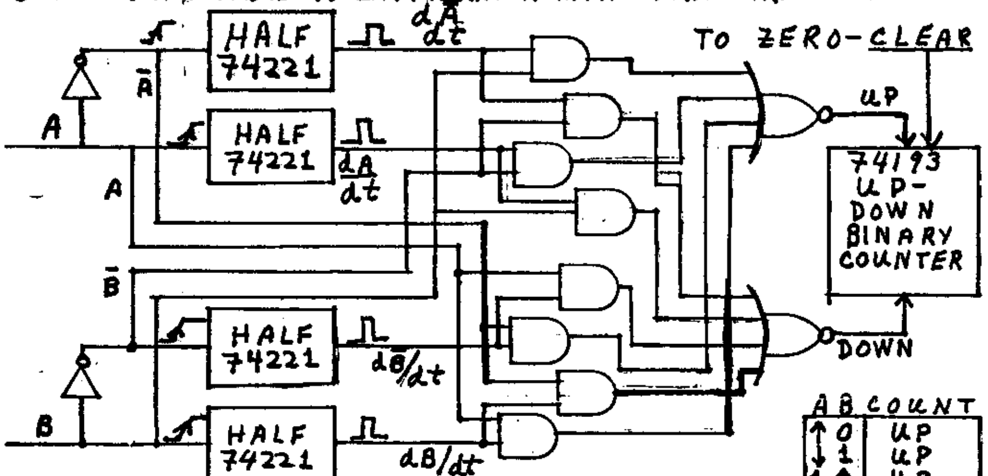
SIDE VIEW - SHOWING TRANSPARENT SLOTS IN MASTER AND SLIDING WINDOWS IN MASK

SIGNALS FROM SATURATED PHOTO DETECTORS HAVE ABOUT 90 DEGREE PHASE DIFFERENCE



FOR TIME AXIS TO RIGHT→ ARROWS SHOW $\frac{dA}{dt}$, $\frac{dB}{dt}$, $\frac{d\bar{A}}{dt}$, $\frac{d\bar{B}}{dt}$ WHERE $\frac{dA}{dt}$ AND $\frac{dB}{dt}$ ARE POSITIVE TRANSITIONS OF A AND B AND $\frac{d\bar{A}}{dt}$ AND $\frac{d\bar{B}}{dt}$ ARE NEGATIVE TRANSITIONS OF A AND B. IF THE TIME AXIS CHANGES DIRECTION OR EQUIVALENTLY RELATIVE MOVEMENT OF MASK AND MASTER INVERTS POSITIVE ↔ NEGATIVE

CIRCUIT FOR KNOWING ACTUAL RELATIVE POSITION - 74221 IS DUAL MONOSTABLE MULTIVIBRATOR WITH SCHMITT TRIGGER INPUT



COUNT UP: (RIGHT) $\bar{B}\frac{dA}{dt} + A\frac{dB}{dt} + B\frac{d\bar{A}}{dt} + \bar{A}\frac{d\bar{B}}{dt}$

COUNT DOWN (LEFT) $\bar{B}\frac{d\bar{A}}{dt} + A\frac{d\bar{B}}{dt} + B\frac{dA}{dt} + \bar{A}\frac{dB}{dt}$

A	B	COUNT
↑	0	UP
↓	1	UP
1	↑	UP
0	↓	UP
↑	1	DOWN
↓	0	DOWN
0	↑	DOWN
1	↓	DOWN