TDS-214 Project:

Conversion From Analog to Digital Tachometer

VLBA Antenna Memo #31

Doug Whiton
12/4/00

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HEDS-5120
LM2907
LM324A

Interoffice

National Radio Astronomy Observatory

Socorro, New Mexico

January 5, 2001

To: Paul Rhodes
From: Douglas Whiton
Subject: VLBA Servo Tachometer Replacement

SUMMARY

The objective of this project is to replace the existing analog tachometers on the VLBA radio telescopes with a digital feedback circuit that is much less susceptible to noise, more reliable over time, less expensive, and less labor intensive.

The current design requires a very expensive DC voltage generator ($610.00 in Grianger). Another problem with the existing tachometer is the noise they generate as they age. Contamination from wear or weather causes excessive noise (> 10 % of maximum voltage or 17.5 V AZ and 25 V EL), which in turn causes great stress on the antenna and the electrical components driving it as the noise ripples through the circuit. Before being shipped to a site, these tachometers require several hours of burn-in at the Servo shop to seat the brushes in an effort to reduce the noise to an acceptable level. At the antenna site there is an extensive PM procedure performed twice a year. Here at Hancock, I think we average replacing at least one tachometer per year.

DESCRIPTION

The following questions had to be considered for the new design.

1. What is required of the new design to interface with the existing circuit?

The new design should have little or no noise. There should be no chance of noise being created later because of wear or weather. We want to make as little change to the existing circuit as possible.

The existing tachometer outputs run through a voltage divider as soon as the signal gets into the servo cabinet. The signal is reduced to +/- 10 volts max. This is where I would prefer to insert the new circuit, actually using the rate feedback buffer op-amps for the final output of the new circuit (Note. 1). Specifically, a reconfiguration of the resistors of the Rate Feedback Buffers to emulate U4b in the schematic of the new circuit (page 4).

2. How much of the existing feedback circuit would be changed or deleted?

I suggest that the A1TB7 be totally redesigned to exclude the voltage divider and nulling circuits, and to include the new circuit up to U4a. There will be two of these "new circuits" on each of the redesigned A1TB7 (Note. 2). To do this, the circuit required would have to put out +/- 10 V at max slew with the polarity indicating direction. With the axis dependent circuitry replacing A1TB7, the Servo Interface Boards would still be interchangeable.

Currently, full voltage from the tachometers is going into the ACU. Changes to the ESI board are necessary to have the Motor Velocity gauges functional on the front panel of the ACU. Also, output of the new circuit will have to be routed to the ESI board instead of a direct connection to the tachometer (Note. 7).

Notes: 1. see NRAO drawing # 85-17065-000 sht.4 for feed back rate buffer
2. see NRAO drawing # 85-17061-000 sht.5 for A1TB7 voltage divider
7. see NRAO drawing # 85-17046-000 sht.3 for motor velocities circuit

The new design uses an Agilent HEDS-9100 encoder matched with the Agilent HEDS-5120 encoder wheel with 360 CPR (cycles per revolution) (Note. 3). I would have preferred 50 CPR, but 360 CPR was the only set in stock at Newark. Channel A of the encoder goes into a LM2907 Frequency to Voltage converter and to the data input of a D-Latch. Channel B of the encoder is the clock input of the latch. The Latch controls an AD7510 Analog Switch, CCW enables switch C, CW enables switch D. The output of the LM2907 is 0 to + 10V. When switch C is enabled (CW), the output of the circuit is positive voltage. When switch D is enabled (CW), the signal gets inverted, making the output a negative voltage.

3. What new power sources would need to be added?

Power supplies required for the new circuit are + and – 15 V, and + 5 V. These voltages are readily available in the servo cabinet. The decoder requires + 5 V. I considered using the existing two wire cable for the new circuit. This would mean that we would have to rectify the + 5 V from the + 24 V present in the motor J-Boxes and would likely cause noise due to a difference in reference ground potentials. To avoid the potential for noise, it will be necessary to run a new 4 wire cable from the Servo cabinet to each of the motors.

4. How linear is the new circuit?

Choosing the correct resistors and capacitors to use in conjunction with the LM2907 is critical to achieve the desired output (Note. 4). Obviously these values will have to be recalculated for the elevation. They will also have to be recalculated if we go with a 50 CPR wheel. Tests of the new circuit showed a very linear output for the frequency to voltage conversion (Note. 5).

5. How much and what kind of noise can be expected?

The noise is a consistent 0.24 V spike corresponding to the rising edge of the input frequency signal (Note. 6). This noise is 2.4% of the signal at full slew, well within the current tachometer specifications. As the speed is reduced, the noise becomes a larger percentage of the signal, but the noise becomes less frequent. The noise frequency is ~ 4 MHz, with a duration of 1 μs. I believe this noise is negligible, but some noise reduction may be necessary. No ripple voltage was detected.

6. Would weather or temperature affect the new circuit?

The only part of the circuit that will be outside is the decoder and wheel. They will be in a weatherproof box, but temperature will not be regulated. The operating range of the encoder is –40C to +100C, easily covering the operating range of the antenna. The rest of the circuit will be in the servo cabinet, where the temperature fluctuates about 10C (from 25C to 35C). Expected output variations due to temperature variations are insignificant.

Notes: 3. see page 4 for new circuit schematic
4. see page 6 for LM2907 resistor and capacitor calculations
5. see page 7 for frequency to voltage plot
6. see page 9 for noise image

7. How much maintenance would the design require?

The circuit should be very stable, but it does require a potentiometer to compensate for capacitor variations and for precision matching of the two motors. This means that there could be some drift over time in the pots.

Calibration of the circuit will be relatively easy. With one motor disabled and the other running at about ¾ speed, a check of the frequency from the encoder will be taken with the oscilloscope or the frequency counter. The circuit output of the active motor will be set to $V_{out} = f * 476\ \mu V$ by adjusting the circuit's pot. (This calculation is for the azimuth circuit with a 360 CPR wheel.) Next, the disabled motor circuit will be set to match V_{out} of the active motor.

I used a 360CPR encoder and metal encoder wheel set. I would have preferred to use a 50 CPR set. I thought of a glass wheel to prevent corrosion, but they are only available at very high (1000 – 2000) CPR. I have not yet been able to find out the material used or the corrosion resistance of the metal wheel.

The encoder wheels are very delicate. The option to an open encoder wheel is an enclosed encoder. The enclosed encoder is more expensive, but much more durable and should be considered. The use of an enclosed encoder would require the existing tachometer coupling.

8. How much does the design cost?

Cost of parts for the circuit was less than $60.00. The encoder and encoder wheel that I used cost less than $50.00. The price of a comparable enclosed encoder is around $250.00 in Newark. The cost of the IC's is about $1.00 each. Another expense will be the new 4 wire cable to the four motors. Modifications to the Servo Interface Board and the ACU ESI Board are small. The tachometer will be eliminated. A weather proof box covering the encoder will have to be fabricated or purchased.

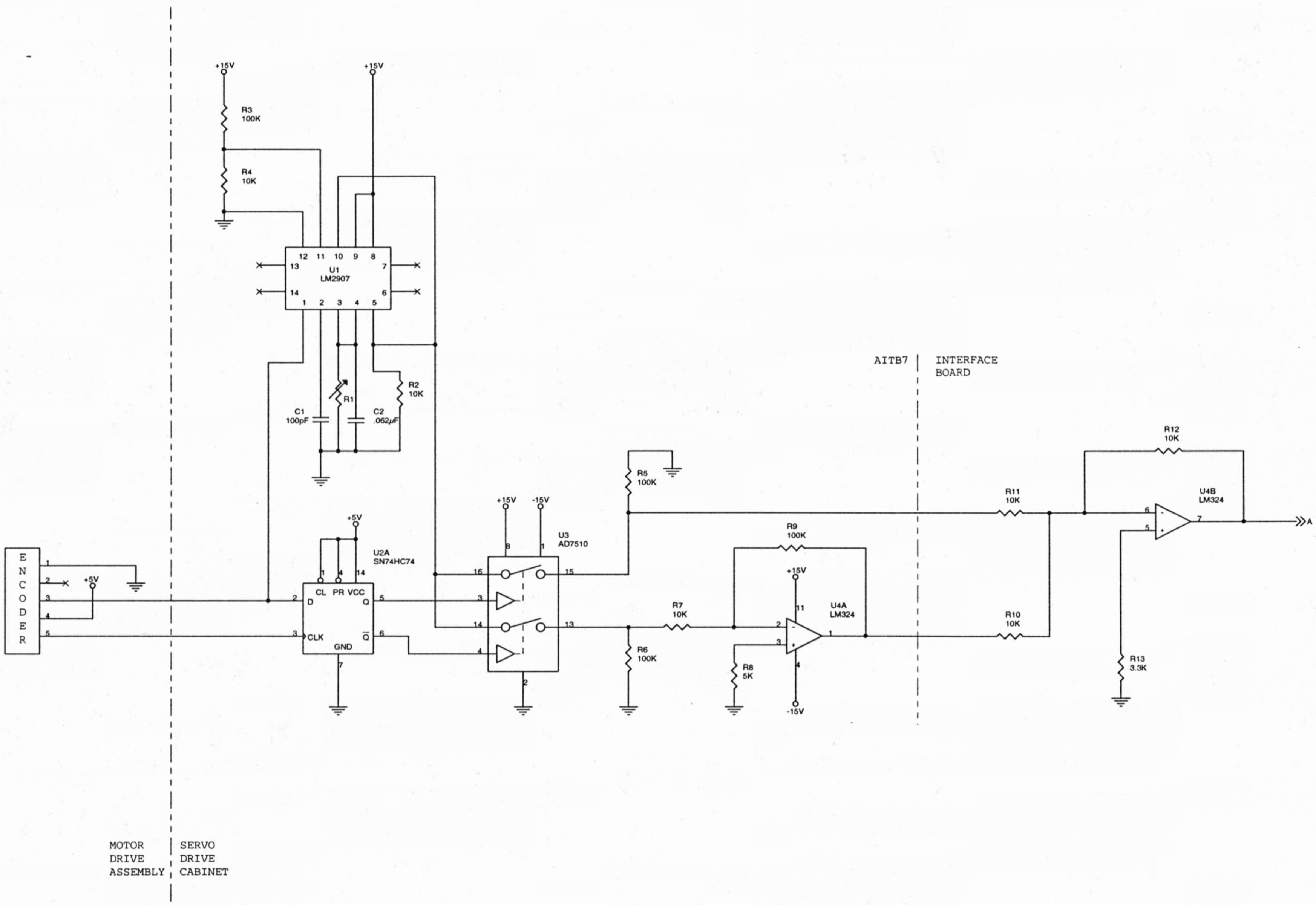
Total cost of the parts will likely be less than $500.00 per motor.

CONCLUSIONS

With the correct selection of resistors and capacitors, the frequency to voltage conversion of the LM2907 is excellent. No ripple voltage was detected. The potential for noise developing is virtually eliminated.

Tests of the new circuit demonstrate the potential of replacing the existing circuit with one that is less susceptible to noise and less expensive is possible. Reliability over time has not been tested, but the general reliability of solid state devices is promising.

There will be some initial labor related costs, but the cost of parts should be well below the cost of a new tachometer. In the long run it seems as though this design would be worth the investment.



REV	DATE	DRAWN BY	APPRV'D BY	DESCRIPTION

ORCAD : 52502S02

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES: ANGLES ±
3 PLACE DECIMALS(.XXX) ±
2 PLACE DECIMALS (.XX) ±
1 PLACE DECIMALS (.X) ±

MATERIAL:

FINISH:

NEXT ASSEMBLY | DWG TYPE

VLBA

PROJECT: SERVO

TITLE: SERVO DIGITAL TACHOMETER SCHEMATIC DIAGRAM

NATIONAL RADIO ASTRONOMY OBSERVATORY

SOCORRO, NEW MEXICO 87801

DRAWN BY	K. TATE	DATE	3/8/01
DESIGNED BY	D. WHITON	DATE	2/27/01
APPROVED BY	D. WHITON	DATE	3/10/01

SHEET NUMBER 1 OF 1 | DRAWING NUMBER C52502S002 | REV - | SCALE NONE

PARTS LIST

Encoder		HGDS-9100-G00
Encoder Wheel		HGDS-5120-G06
U1	Frequent to volt converter	LM2907
U2	D type flip flop	SN74H74
U3	Analog switch	AD7510
U4	Low power OP-Amp	LM324
R1	Ideally 317.5 K Ohm (Used 50 K pot with 270 K and 100 K resistor in series)	
R2	10 K Ohm	
R3	100 K Ohm	
R4	10 K Ohm	
R5	100 K Ohm	
R6	100 K Ohm	
R7	10 K Ohm	
R8	5 K Ohm	
R9	10 K Ohm	
R10	10 K Ohm	
R11	10 K Ohm	
R12	10 K Ohm	
R13	3.3 K Ohm	
C1	100 pf	
C2	.062 uf (Used .068 uf)	

Calculations

$V_{out} = f_{in} * Vcc * R1 * C1$

$V_{out} = V_{3max} = 10v$; $Vcc = 15v$; $f_{in} = 21000Hz$

$C1_{vout} = 100pf$

$R1_{vout} = 317K\Omega$

$C2_{vripple} = .062\mu f$ (use $.068\mu f$)

$$R1 \geq \frac{V3_{max}}{I3_{min}} = \frac{10v}{150\mu A} = 66k\Omega$$

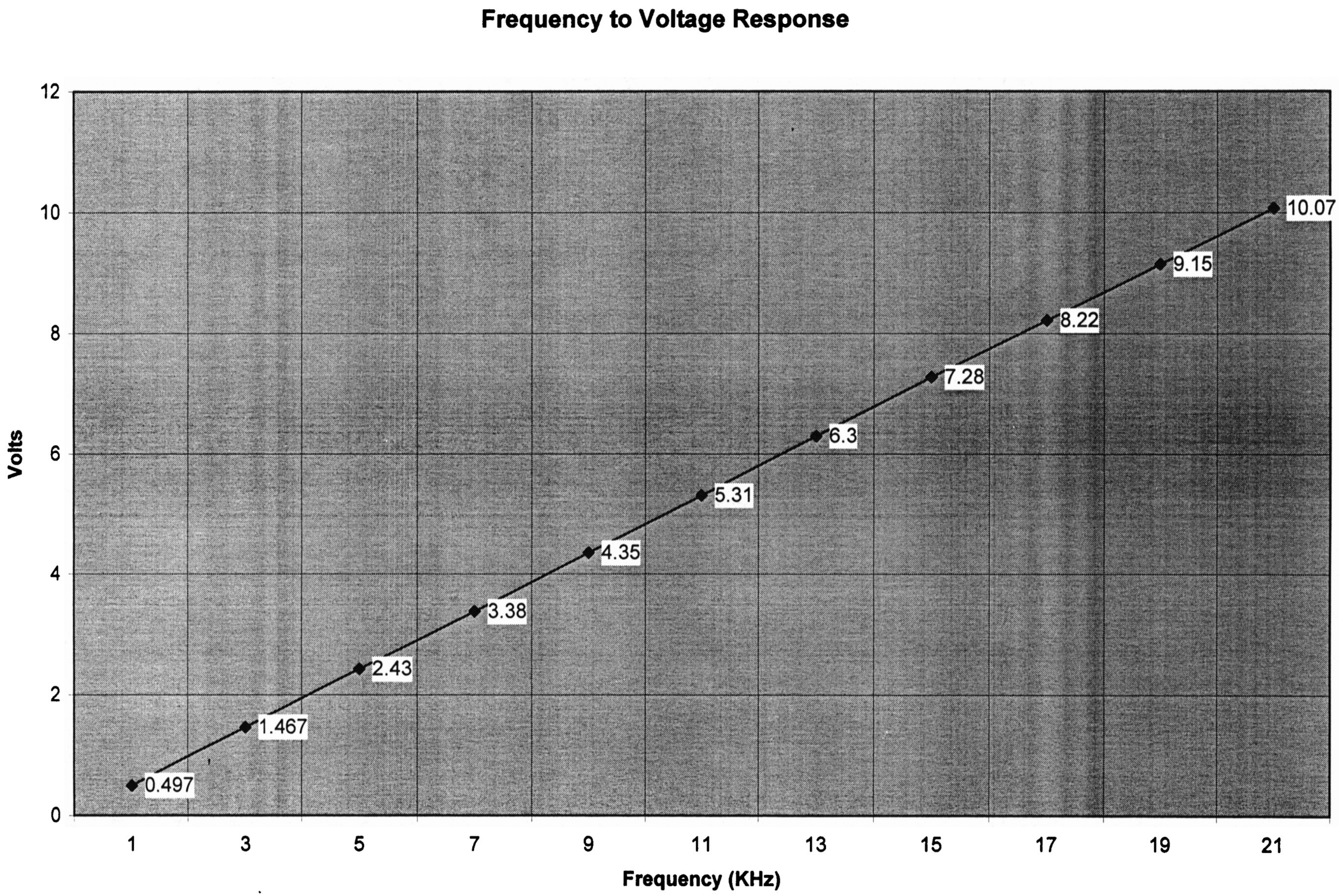
$C1 = 100pf$

$$R1 = \frac{V_{3max}}{f_{in} * Vcc * C1} = \frac{10}{2100 * 15 * 100pf} = 317460\Omega$$

$$C2 = \frac{Vcc}{2} * \frac{C1}{V_{ripple}} * \left(1 - \frac{V3}{R1 * I2}\right) = .062\mu f$$

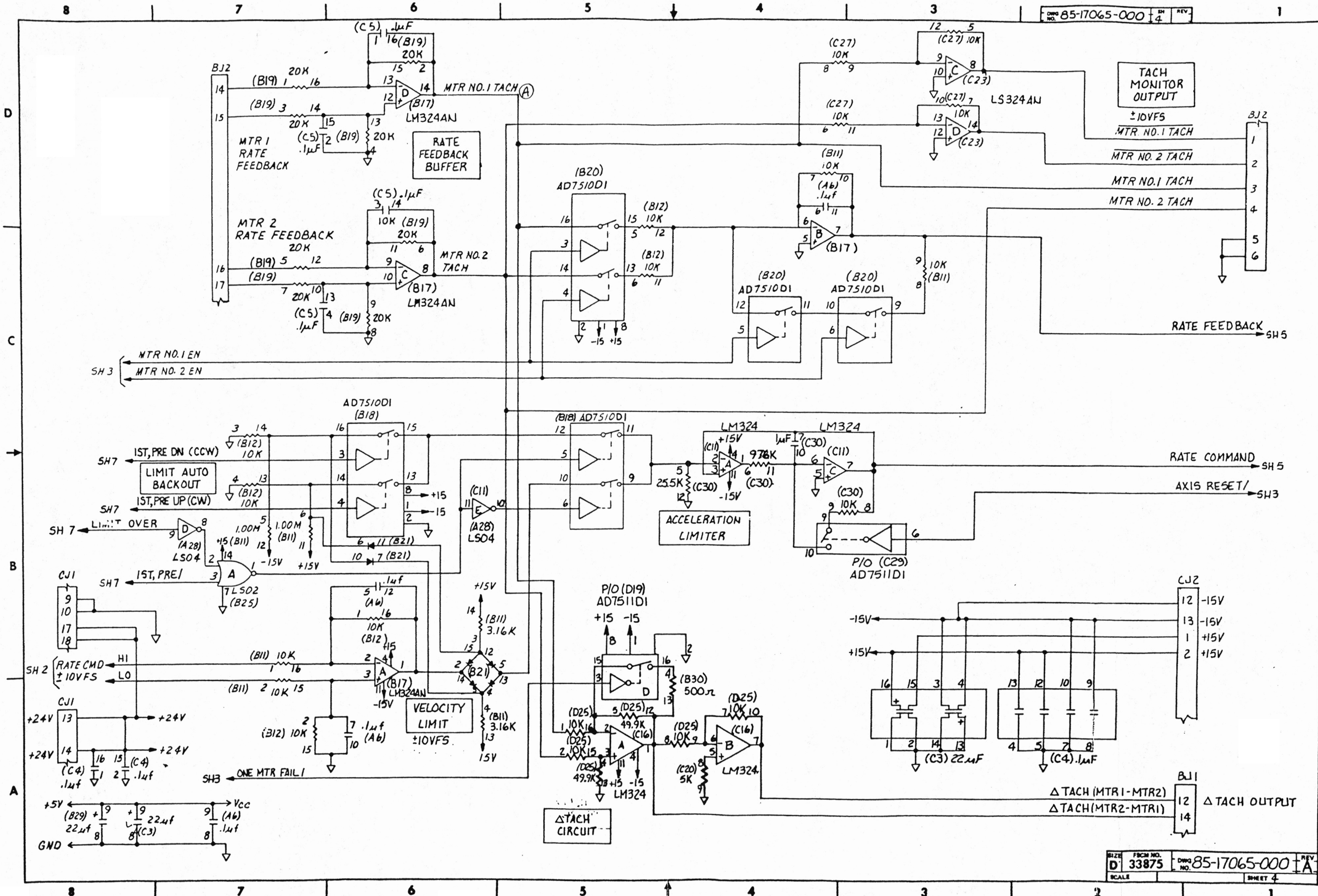
$V_{ripple} = .1\%$ of $V_{out} = .01v$

$I_2 = 180\mu A$ typ.

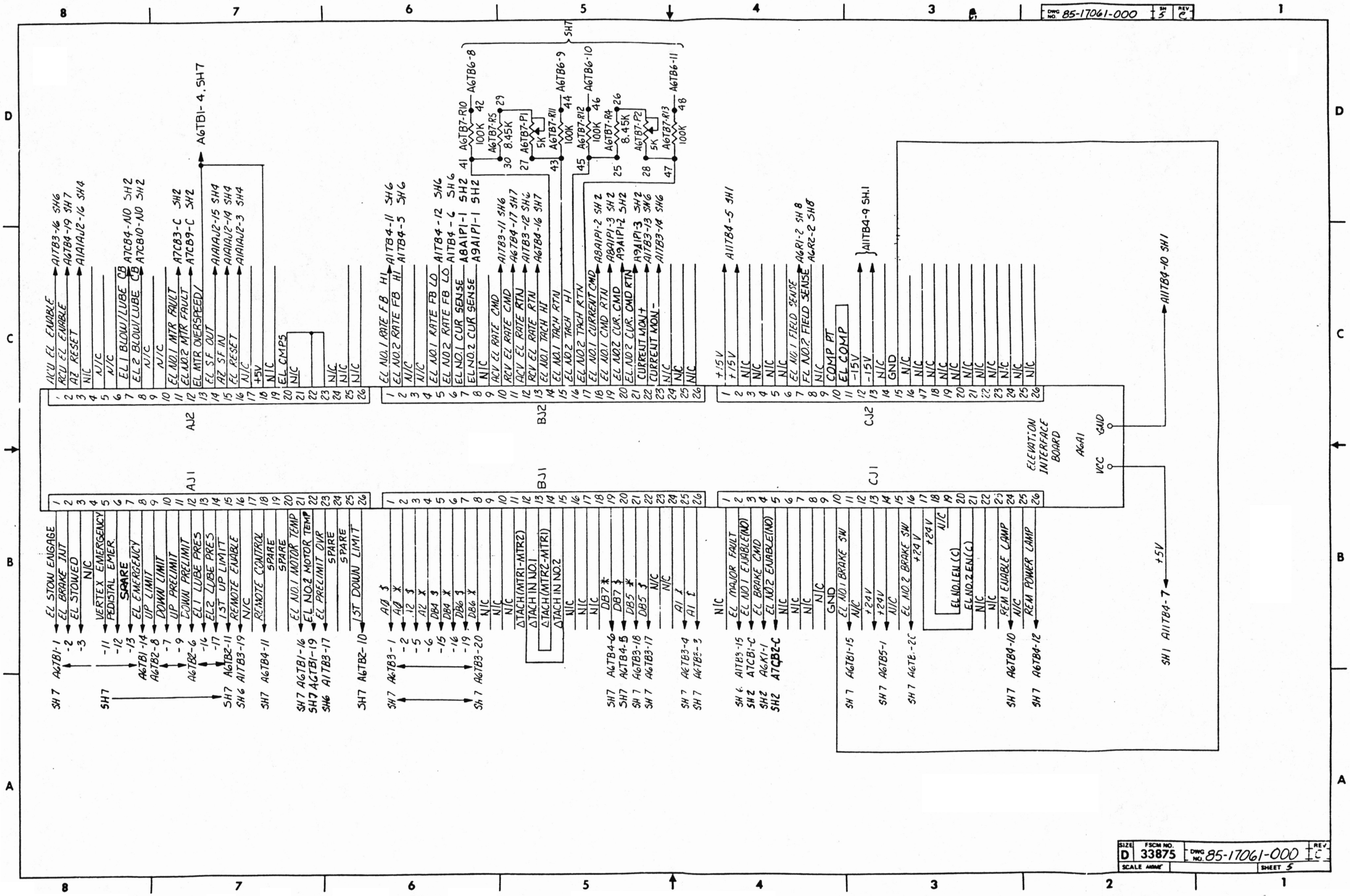

Frequency to Voltage Response
Volts
Frequency (KHz)
12
10
8
6
4
2
0
1
3
5
7
9
11
13
15
17
19
21
0.497
1.467
2.43
3.38
4.35
5.31
6.3
7.28
8.22
9.15
10.07

CIRCUIT LINEARITY TEST DATA

Frequency In (+1%)	VOUT	
fIN	CW	CCW
1 k	-.501	.497
3 k	-1.474	1.467
5 k	-2.44	2.43
7 k	-3.39	3.38
9 k	-4.37	4.35
11 k	-5.33	5.31
13 k	-6.32	6.30
15 k	-7.30	7.28
17 k	-8.24	8.22
19 k	-9.18	9.15
21 k	-10.10	10.07



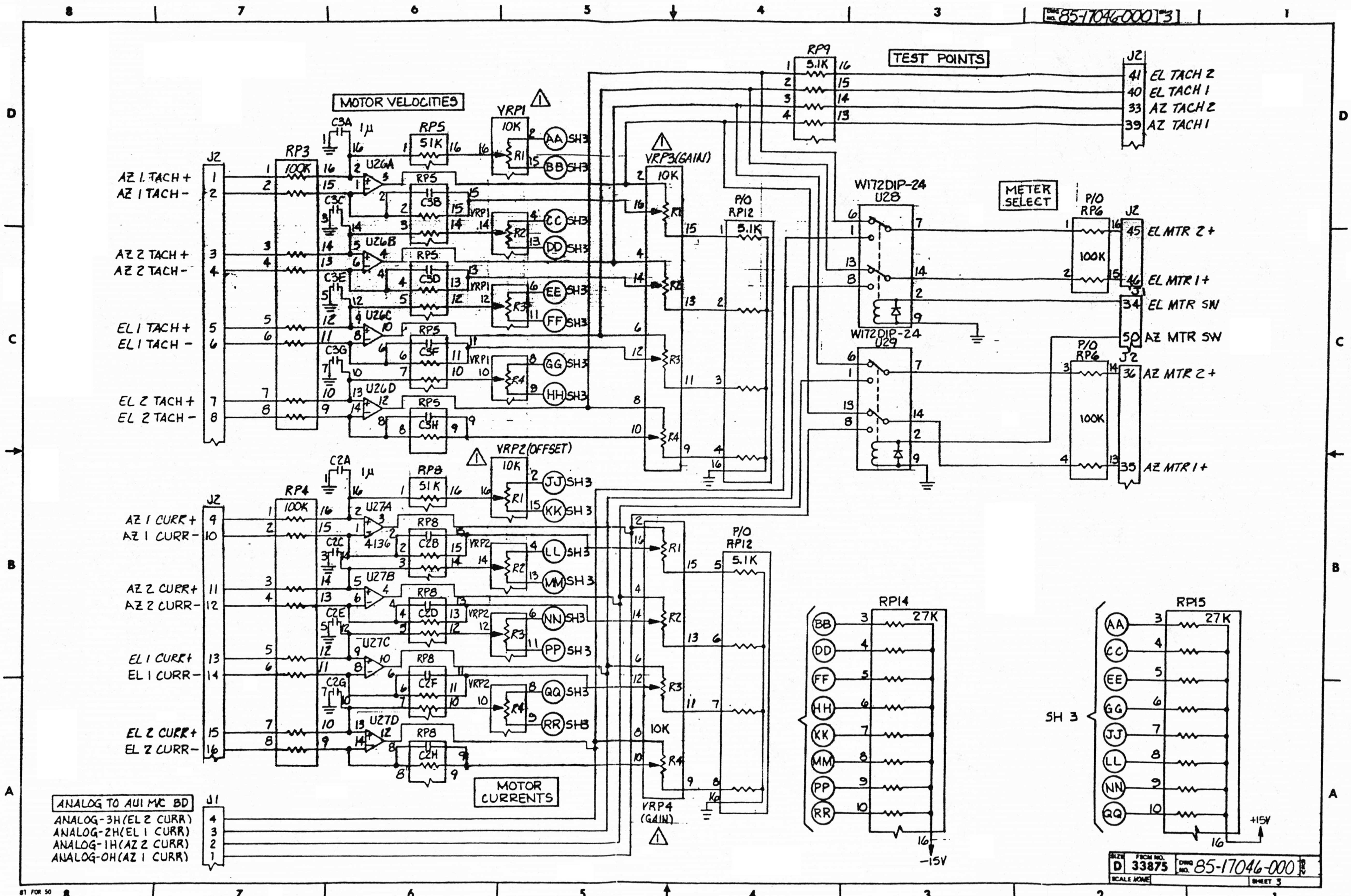
85-17065-000 SH 4
BJ2
MTR 1 RATE FEEDBACK
MTR 2 RATE FEEDBACK
RATE FEEDBACK BUFFER
MTR NO.1 TACH
MTR NO.2 TACH
LM324AN
LS324AN
TACH MONITOR OUTPUT
±10VFS
MTR. NO.1 TACH
MTR NO. 2 TACH
MTR NO.1 TACH
MTR NO. 2 TACH
AD7510D1
RATE FEEDBACK
SH5
SH 3
MTR NO.1 EN
MTR NO. 2 EN
SH7
1ST, PRE DN (CCW)
LIMIT AUTO BACKOUT
1ST, PRE UP (CW)
LIMIT OVER
SH 7
1ST, PRE/
LS04
LS02
CJ1
SH 2
RATE CMD
±10VFS
HI
LO
VELOCITY LIMIT
±10VFS
+24V
+5V
Vcc
GND
SH3
ONE MTR FAIL/
ACCELERATION LIMITER
LM324
RATE COMMAND
AXIS RESET/
P/O (C29) AD7511D1
P/O (D19) AD7511D1
ΔTACH CIRCUIT
CJ2
-15V
+15V
(C3) 22μF
(C4) .1μF
BJ1
ΔTACH (MTR1-MTR2)
ΔTACH (MTR2-MTR1)
ΔTACH OUTPUT
SIZE D
FSCM NO. 33875
DWG NO. 85-17065-000
REV A
SCALE
SHEET 4



DWG NO. 85-17061-000 SH 5 REV C

SIZE D FSCM NO. 33875 DWG NO. 85-17061-000 REV C

SCALE NONE SHEET 5



85-17046-000 3
MOTOR VELOCITIES
TEST POINTS
METER SELECT
MOTOR CURRENTS
AZ 1 TACH +
AZ 1 TACH -
AZ 2 TACH +
AZ 2 TACH -
EL 1 TACH +
EL 1 TACH -
EL 2 TACH +
EL 2 TACH -
AZ 1 CURR +
AZ 1 CURR -
AZ 2 CURR +
AZ 2 CURR -
EL 1 CURR +
EL 1 CURR -
EL 2 CURR +
EL 2 CURR -
EL TACH 2
EL TACH 1
AZ TACH 2
AZ TACH 1
EL MTR 2 +
EL MTR 1 +
EL MTR SW
AZ MTR SW
AZ MTR 2 +
AZ MTR 1 +
VRP1 10K
VRP2 (OFFSET) 10K
VRP3 (GAIN) 10K
VRP4 (GAIN)
W172DIP-24 U28
W172DIP-24 U29
RP3 100K
RP4 100K
RP5 51K
RP8 51K
RP9 5.1K
P/O RP12 5.1K
P/O RP6 100K
RP14 27K
RP15 27K
SH 3
-15V
+15V
ANALOG TO AUI M/C BD
ANALOG-3H (EL 2 CURR)
ANALOG-2H (EL 1 CURR)
ANALOG-1H (AZ 2 CURR)
ANALOG-0H (AZ 1 CURR)
D 33875 85-17046-000
SCALE NONE
SHEET 3

Agilent Technologies
Innovating the HP Way

Two Channel High Resolution Optical Incremental Encoder Modules

Technical Data

HEDS-9000/9100/9200 Extended Resolution Series

Features

- **High Resolution: Up to 2048 Cycles per Revolution**
- **Up to 8192 Counts per Revolution with 4X Decoding**
- **Two Channel Quadrature Output**
- **Low Cost**
- **Easy to Mount**
- **No Signal Adjustment Required**
- **Small Size**
- **-40°C to 100°C Operating Temperature**
- **TTL Compatible**
- **Single 5 V Supply**

Description

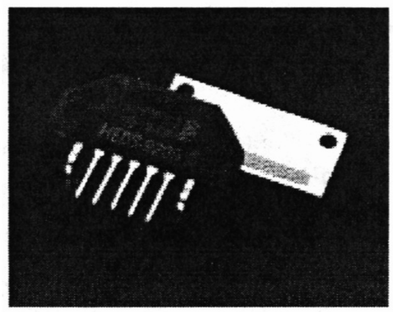
The HEDS-9000 Options T and U and the HEDS-9100 Options B and J are high resolution two channel rotary incremental encoder modules. These options are an extension of our popular HEDS-9000 and HEDS-9100 series. When used with a codewheel, these modules detect relative rotary position. The HEDS-9200 Option 300 and 360 are high resolution linear encoder modules. When used with a codestrip, these modules detect relative linear position.

These modules consist of a lensed Light Emitting Diode (LED) source and detector IC enclosed in a small C shaped plastic package. Due to a highly collimated light source and unique photodetector array, these modules provide a highly reliable quadrature output.

The HEDS-9000 and HEDS-9100 are designed for use with codewheels which have an optical radius of 23.36 mm and 11 mm respectively. The HEDS-9200 is designed for use with a linear codestrip.

These components produce a two channel quadrature output which can be accessed through five 0.025 inch square pins located on 0.1 inch centers.

The resolution of the HEDS-9000 Options T and U are 2000 and 2048 counts per revolution respectively. The HEDS-9100 Options B and J are 1000 and 1024 counts per revolution respectively. The HEDS-9200 Option 300 and 360 linear encoder modules have resolutions of 300 and 360 lines per inch.



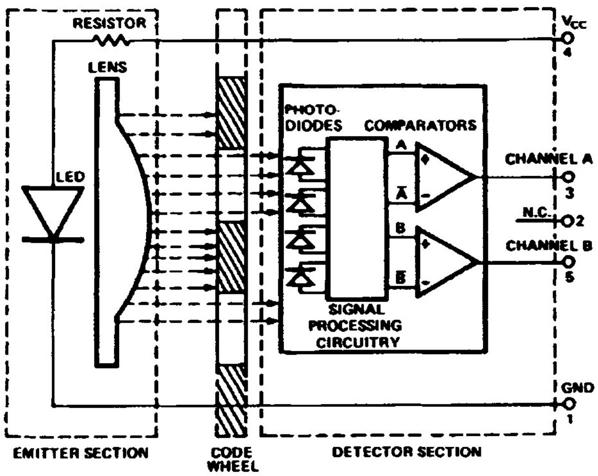
Consult local Agilent sales representatives for other resolutions.

Theory of Operation

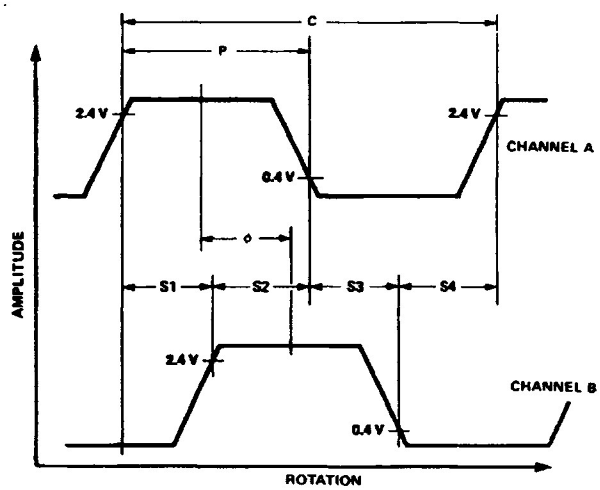
The diagram shown on the following page is a block diagram of the encoder module. As seen in this block diagram, the module contains a single LED as its light source. The light is collimated into a parallel beam by means of a single polycarbonate lens located directly over the LED. Opposite the emitter is the integrated detector circuit. This IC consists

ESD WARNING: NORMAL HANDLING PRECAUTIONS SHOULD BE TAKEN TO AVOID STATIC DISCHARGE.

Block Diagram



Output Waveforms



of multiple sets of photodetectors and the signal processing circuitry necessary to produce the digital waveforms.

The codewheel/codestrip passes between the emitter and detector, causing the light beam to be interrupted by the pattern of spaces and bars on the code-wheel. The photodiodes which detect these interruptions are arranged in a pattern that corresponds to the codewheel/codestrip. These detectors are also spaced such that a light period on one pair of detectors corresponds to a dark period on the adjacent pair of detectors. The photodiode outputs are then fed through the signal processing circuitry resulting in A, $\overline{A}$, B, and $\overline{B}$. Comparators receive these signals and produce the final outputs for channels A and B. Due to this integrated phasing technique, the digital output of channel A is in quadrature with that of channel B (90 degrees out of phase).

Definitions

Count (N): The number of bar and window pairs or counts per revolution (CPR) of the codewheel.

1 cycle (C): 360 electrical degrees (°e), 1 bar and window pair.

1 Shaft Rotation: 360 mechanical degrees, N cycles.

Pulse Width (P): The number of electrical degrees that an output is high during 1 cycle. This value is nominally 180°e or 1/2 cycle.

Pulse Width Error (ΔP): The deviation, in electrical degrees of the pulse width from its ideal value of 180°e.

State Width (S): The number of electrical degrees between a transition in the output of channel A and the neighboring transition in the output of channel B. There are 4 states per cycle, each nominally 90°e.

State Width Error (ΔS): The deviation, in electrical degrees, of each state width from its ideal value of 90°e.

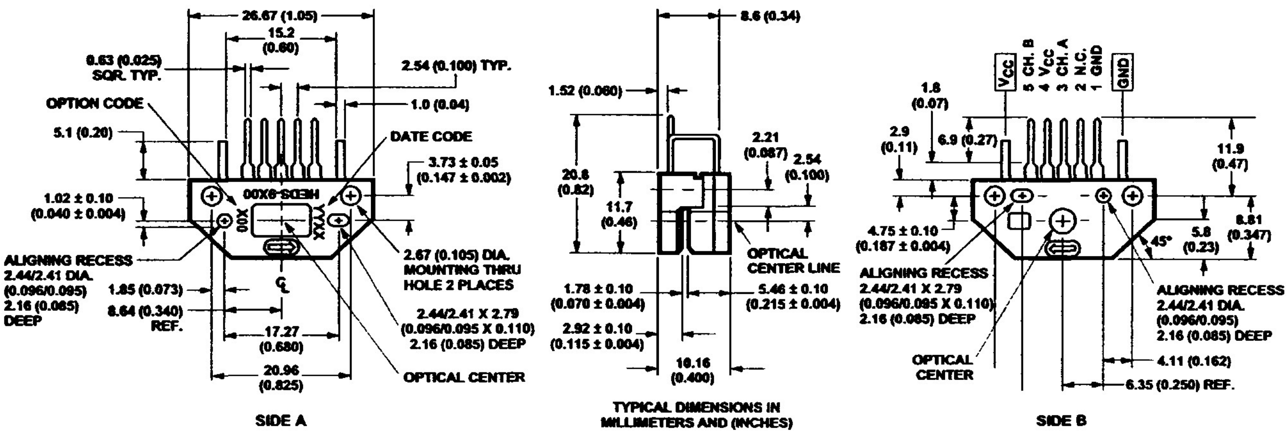
Phase (ϕ): The number of electrical degrees between the center of the high state of channel A and the center of the high state of channel B. This value is nominally 90°e for quadrature output.

Phase Error (Δϕ): The deviation of the phase from its ideal value of 90°e.

Direction of Rotation: When the codewheel rotates in the direction of the arrow on top of the module, channel A will lead channel B. If the codewheel rotates in the opposite direction, channel B will lead channel A.

Optical Radius (R_{op}): The distance from the codewheel's center of rotation to the optical center (O.C.) of the encoder module.

Package Dimensions



Absolute Maximum Ratings

Storage Temperature, T_S .... -40°C to 100°C
Operating Temperature, T_A .... -40°C to 100°C
Supply Voltage, V_{CC} .... -0.5 V to 7 V
Output Voltage, V_O .... -0.5 V to V_{CC}
Output Current per Channel, I_{out} .... -1.0 mA to 5 mA

Recommended Operating Conditions

Parameter	Symbol	Min.	Typ.	Max.	Units	Notes
Temperature	T_A	-40		100	°C	
Supply Voltage	V_{CC}	4.5	5.0	5.5	Volts	Ripple < 100 mV_{p-p}
Load Capacitance	C_L			100	pF	3.3 kΩ pull-up resistor
Count Frequency	f			100	kHz	Velocity (rpm) x N/60
Shaft Axial Play				± 0.125 ± 0.005	mm in.	

Note: The module performance is guaranteed to 100 kHz but can operate at higher frequencies. For frequencies above 100 kHz it is recommended that the load capacitance not exceed 25 pF and the pull up resistance not exceed 3.3 kΩ. For typical module performance above 100 kHz please see derating curves.

Electrical Characteristics

Electrical Characteristics over Recommended Operating Range, typical at 25°C.

Parameter	Symbol	Min.	Typical	Max.	Units	Notes
Supply Current	I_{CC}	30	57	85	mA	
High Level Output Voltage	V_{OH}	2.4			Volts	I_{OH} = -200 μA max.
Low Level Output Voltage	V_{OL}			0.4	Volts	I_{OL} = 3.86 mA
Rise Time	t_r		180		ns	C_L = 25 pF R_L = 3.3 kΩ pull-up
Fall Time	t_f		40		ns	

Encoding Characteristics

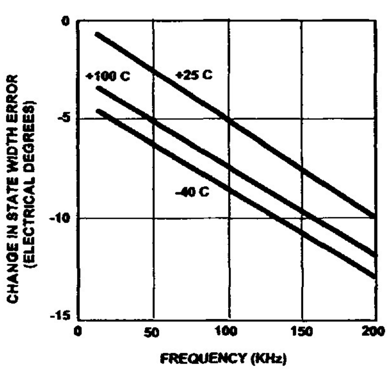
Encoding Characteristics over Recommended Operating Range and Recommended Mounting Tolerances. These Characteristics do not include codewheel/codestrip contribution. The Typical Values are averages over the full rotation of the codewheel. For operation above 100 kHz, see frequency derating curves.

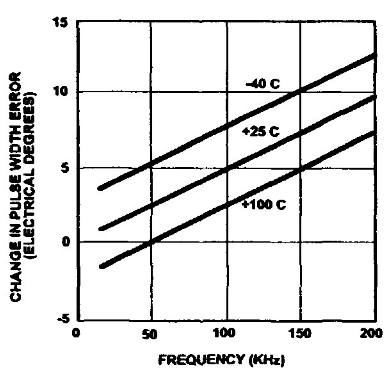
Description	Symbol	Typical	Maximum	Units
Pulse Width Error	ΔP	5	45	°e
Logic State Width Error	ΔS	3	45	°e
Phase Error	Δφ	2	15	°e

Note: Module mounted on tolerance circle of ± 0.13 mm (± 0.005 in.) radius referenced from module Side A aligning recess centers. 3.3 kΩ pull-up resistors used on all encoder module outputs.

Frequency Derating Curves

Typical performance over extended operating range. These curves were derived using a 25 pF load with a 3.3 k pull-up resistor. Greater load capacitances will cause more error than shown in these graphs.





Gap Setting for Rotary and Linear Modules

Gap is the distance between the image side of the codewheel and the detector surface of the module. This gap dimension must always be met and codewheel warp and shaft end play must stay within this range. This dimension is shown in Figure 1.

Mounting Considerations for Rotary Modules

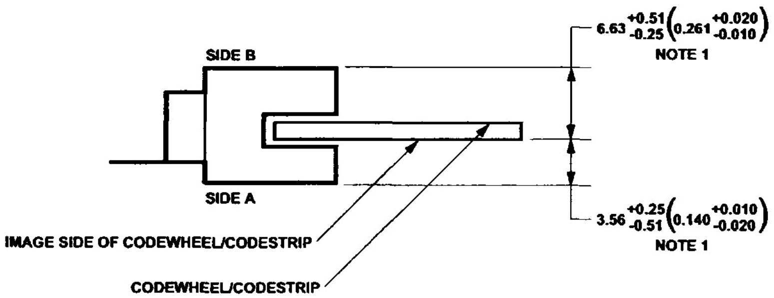
Figure 2 shows a mounting tolerance *requirement* for proper operation of the high resolution rotary encoder modules. The Aligning Recess Centers must be located within a tolerance circle of 0.13 mm (0.005 in.) radius from the nominal locations. This tolerance must be maintained whether the module is mounted with side A as the mounting plane using aligning pins (see Figure 3), or mounted with Side B as the mounting plane using an alignment tool.

Mounting with Aligning Pins

The high resolution rotary encoder modules can be mounted using aligning pins on the motor base. (Agilent does not provide aligning pins.) For this configuration, Side A *must* be used as the mounting plane. The Aligning Recess Centers must be located within the 0.13 mm (0.005 in.) R Tolerance Circle as explained above. Figure 3 shows the necessary dimensions.

Mounting with Alignment Tools

Agilent offers alignment tools for mounting Agilent encoder modules in conjunction with Agilent codewheels, using side B as the mounting plane. Please refer to the Agilent codewheel data sheet for more information.



NOTES: 1. THESE DIMENSIONS INCLUDE CODEWHEEL/CODESTRIP WARP AND SHAFT END PLAY.
2. DIMENSIONS IN MILLIMETERS AND (INCHES).

Figure 1. Module Gap Setting.

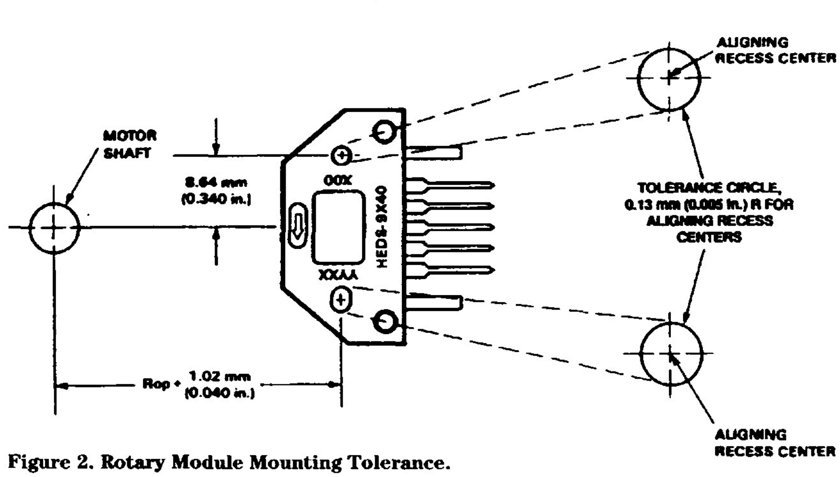
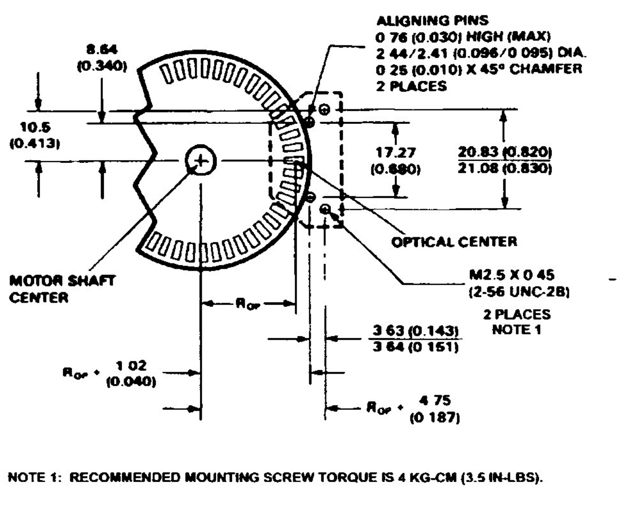


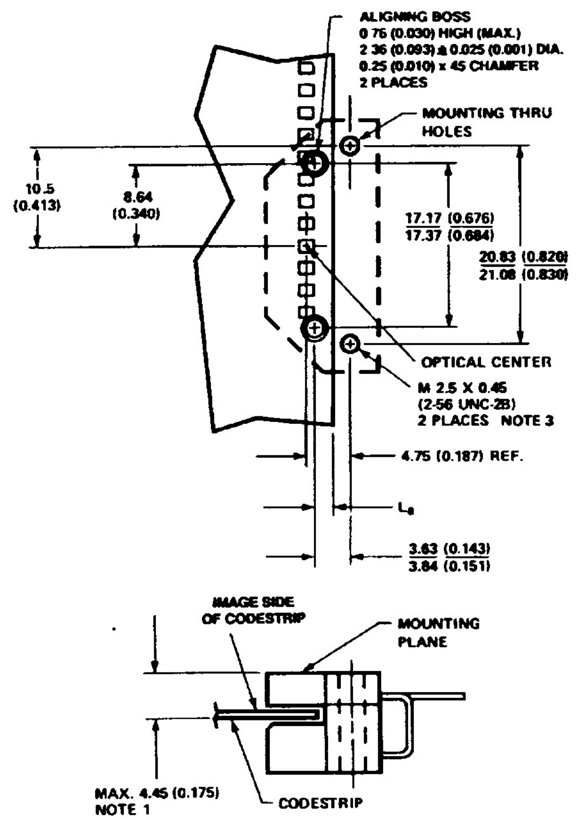
Figure 2. Rotary Module Mounting Tolerance.



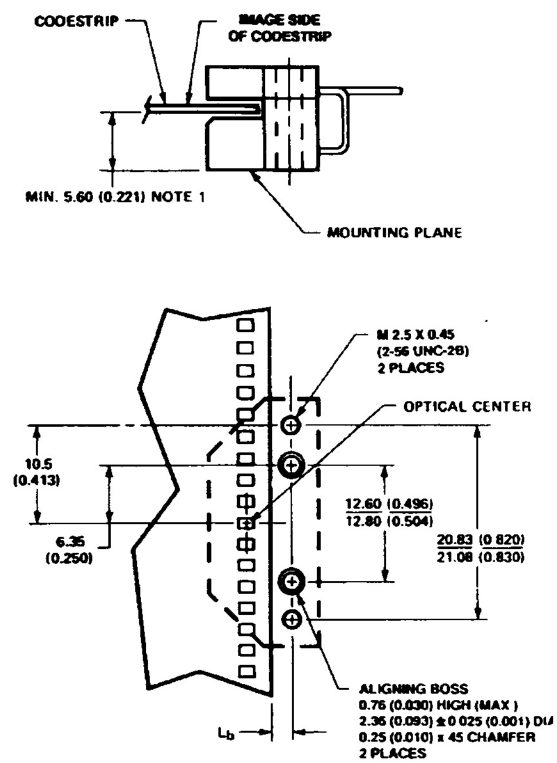
NOTE 1: RECOMMENDED MOUNTING SCREW TORQUE IS 4 KG-CM (3.5 IN-LBS).

Figure 3. Mounting Plane Side A.

Mounting Considerations for Linear Modules



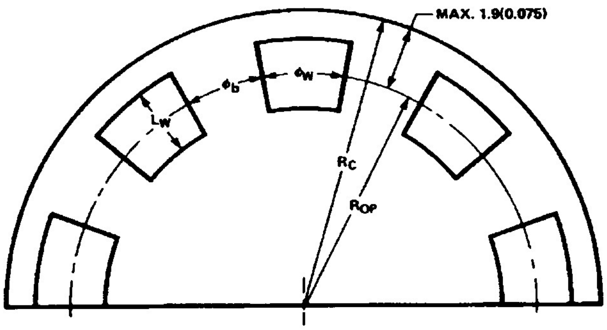
Mounting Plane Side A



Mounting Plane Side B

NOTES:
1. THESE DIMENSIONS INCLUDE CODESTRIP WARP.
2. REFERENCE DEFINITIONS OF L_a AND L_b ON THE FOLLOWING PAGE.
3. MAXIMUM RECOMMENDED MOUNTING SCREW TORQUE IS 4 kg-cm (3.5 in-lbs).

Recommended Codewheel Characteristics



Parameter	Symbol	Minimum	Maximum	Units	Notes
Window/Bar Ratio	ϕ_w/ϕ_b	0.7	1.4		
Window Length	L_w	1.8 (0.07)		mm (inch)	
Absolute Maximum Codewheel Radius	R_c		R_{op} + 1.9 (0.075)	mm (inch)	Includes eccentricity errors

Recommended Codestrip Characteristics and Alignment

Codestrip design must take into consideration mounting as referenced to either side A *or* side B (see Figure 4).

Mounting as Referenced to Side A **Mounting as Referenced to Side B**

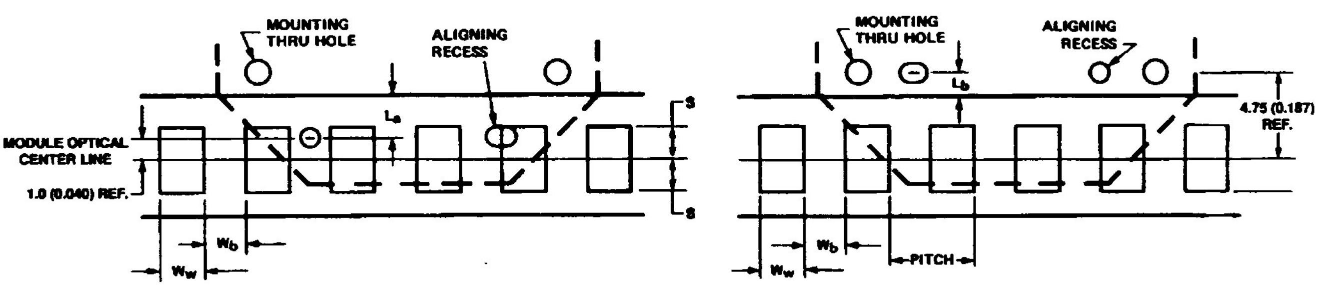


Figure 4. Codestrip Design

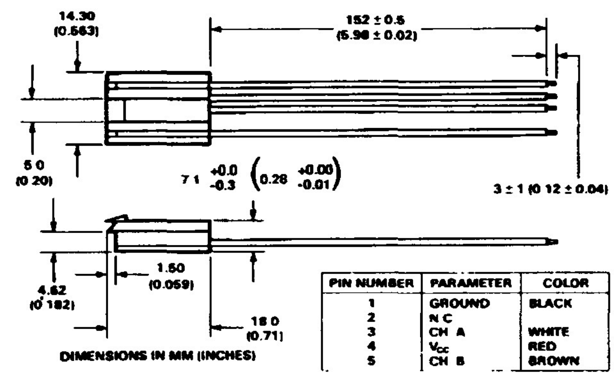
STATIC CHARGE WARNING: LARGE STATIC CHARGE ON CODESTRIP MAY HARM MODULE. PREVENT ACCUMULATION OF CHARGE.

Parameter	Symbol	Mounting Ref. Side A	Mounting Ref. Side B	Units
Window/Bar Ratio	W_w/W_b	0.7 min., 1.4 max.	0.7 min., 1.4 max.	
Window Distance	L	$L_a \leq 0.51$ (0.020)	$L_b \geq 3.23$ (0.127)	mm (inch)
Window Edge to Module Opt Center Line	S	0.90 (0.035) min.	0.90 (0.035) min.	mm (inch)
Parallelism Module to Codestrip	α	1.3 max.	1.3 max.	deg.

Note: All parameters and equations must be satisfied over the full length of codestrip travel including maximum codestrip runout.

Connectors

Manufacturer	Part Number	Mounting Surface
AMP	103686-4 640442-5	Both Side B
DuPont	65039-032 with 4825X-000 term.	Both
Agilent	HEDS-8902 with 4-wire leads	Side B (see Fig. 7)
Molex	2695 series with 2759 series term.	Side B



PIN NUMBER	PARAMETER	COLOR
1	GROUND	BLACK
2	N C	
3	CH A	WHITE
4	V_{CC}	RED
5	CH B	BROWN

Figure 7. HEDS-8902 Connector.

Ordering Information

Two Channel Encoder Modules with a 23.36 mm Optical Radius

HEDS-9000 Option ☐ **0 0**

Resolution (Cycles/Rev)
T - 2000 CPR
U - 2048 CPR

*

Two Channel Encoder Modules with an 11.00 mm Optical Radius

HEDS-9100 Option ☐ **0 0**

Resolution (Cycles/Rev)
B - 1000 CPR
J - 1024 CPR

*

Two Channel Linear Encoder Module

HEDS-9200 Option ☐☐☐

Resolution (Cycles/Rev)
300 - 300 LPI
360 - 360 LPI

Note: For lower resolutions, please refer to HEDS-9000/9100 and HEDS-9200 data sheets for detailed information.

*Codewheel Information

For information on matching codewheels and accessories for use with Agilent rotary encoder modules, please refer to the Agilent Codewheel Data sheet HEDS-5120/6100, HEDG-5120/6120, HEDM-5120/6120

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Obsoletes 5091-7275E (7/93)

5965-5889E (11/99)

Agilent Technologies
Innovating the HP Way

Two and Three Channel Codewheels for use with Agilent Optical Encoder Modules

Technical Data

HEDS-51X0/61X0 Series
HEDG-512X/612X Series
HEDM-512X/61XX Series

Features:

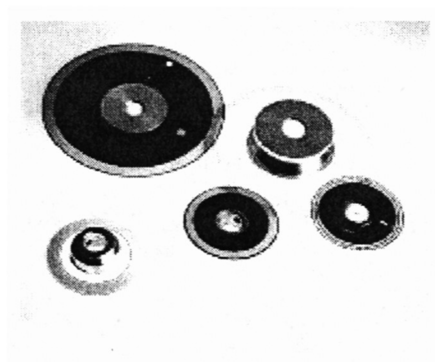
- **Codewheels Available in Glass, Film, and Metal**
- **Available in Two Standard Diameters**
- **Cost Effective**
- **Resolutions from 96 CPR to 2048 CPR**
- **For Use with HEDS-90XX/91XX Series Two and Three Channel Encoders**

Description

Agilent Technologies offers a wide variety of codewheels for use with Agilent's HEDS-9000, HEDS-9100, HEDS-9040, and HEDS-9140 series Encoder Modules. Designed for many environments, applications, and budgets, Agilent codewheels are available in Glass, Film, and Metal. These codewheels are available in resolutions from 96 Counts Per Revolution (CPR) to 1024 CPR on an 11 mm optical radius and 500 to 2048 CPR on a 23.36 mm optical radius.

Each of the three codewheel materials offers a certain advantage. Metal codewheels are the most versatile, with a temperature rating up to 100°C, resolution to 512 CPR (28 mm diameter), as well as 2 and 3 channel outputs. Film codewheels offer higher resolution (up to 1024 CPR on a 28 mm diameter) with an operating temperature of 70°C. Glass codewheels combine the best of film and metal, offering a temperature rating of 100°C and resolutions to 1024 CPR on a 28 mm diameter.

In addition, each material offers a specific reliability rating. It is important to consider the specific application operating environment, long term operating conditions, and temperature ranges when choosing a codewheel material.



Also See:

- HEDS-9000/HEDS-9100 Encoder Module Data Sheet
- HEDS-9000/9100/9200 Extended Resolution Encoder Module Data Sheet
- HEDS-9040/9140 Three Channel Encoder Module Data Sheet
- HEDS-9700 Small Encoder Module Data Sheet

Absolute Maximum Ratings

It is important to consider the environment in which the codewheels will be used when selecting a codewheel material. In brief, metal codewheels are rugged, but do not offer higher resolution capabilities. Film codewheels allow higher resolution, but cannot endure the same temperatures and high humidity as metal. Glass codewheels offer both high temperature and higher resolution, but are also more expensive. Consider the following rating table when choosing a codewheel material.

Parameter	Symbol	HEDS-XXXX Metal Codewheels	HEDM-XXXX Film Codewheels	HEDG-XXXX Glass Codewheels
Storage Temperature	T_S	-40°C to +100°C	-40°C to +70°C	-40°C to +100°C
Operating Temperature	T_A	-40°C to +100°C	-40°C to +70°C	-40°C to +100°C
Humidity			non condensing	
Velocity		30,000 RPM	30,000 RPM	12,000 RPM
Shaft Axial Play		± 0.25 mm (± 0.010 in)	± 0.175 mm (± 0.007 in)	± 0.175 mm (± 0.007 in)
Shaft Eccentricity Plus Radial Play		± 0.1 mm (± 0.004 in) TIR	± 0.04 mm (± 0.0015 in) TIR	± 0.04 mm (± 0.0015 in) TIR
Acceleration		250,000 Rad/Sec^2	250,000 Rad/Sec^2	100,000 Rad/Sec^2

Recommended Operating Conditions

Parameter	HEDS-XXXX Metal Codewheels	HEDM-XXXX Film Codewheels	HEDG-XXXX Glass Codewheels
Maximum Count Frequency	100 kHz	200 kHz*	200 kHz
Shaft Perpendicularity Plus Axial Play	± 0.25 mm (± 0.010 in)	± 0.175 mm (± 0.007 in)	± 0.175 mm (± 0.007 in)
Shaft Eccentricity Plus Radial Play	± 0.1 mm (± 0.004 in) TIR	± 0.04 mm (± 0.0015 in) TIR	± 0.04 mm (± 0.0015 in) TIR

Note: Agilent Encoder Modules are guaranteed to 100 kHz, but can operate at higher frequencies. See Encoder Module Data Sheet for specifications and output load recommendations.

*HEDM-6140 is guaranteed to 100 kHz with the HEDS-9040 #T00 module.

Encoding Characteristics

Encoding characteristics over recommended operating range and recommended mounting tolerances unless otherwise specified. Values are for worst error over a full rotation. Please refer to Encoder Module Data Sheet for definitions of Encoding characteristics.

Part Number	Description	Symbol	Min.	Typ.	Max.	Units
HEDS-51XX	Cycle Error Position Error	ΔC Δθ		3 10	5.5 40	°e min. of arc
HEDS-61XX	Cycle Error Position Error	ΔC Δθ		3 7	5.5 20	°e min. of arc
HEDM-512X	Cycle Error Position Error	ΔC Δθ		3 4	7.5 40	°e min. of arc
HEDM-61XX	Cycle Error Position Error	ΔC Δθ		3 2	7.5 20	°e min. of arc
HEDG-512X	Cycle Error Position Error	ΔC Δθ		3 4	7.5 30	°e min. of arc
HEDG-612X	Cycle Error Position Error	ΔC Δθ		3 2	7.5 15	°e min. of arc

Reliability

In addition to the absolute maximum specifications of codewheels, the environment characteristics of the application are also important. For example, consistent, large temperature swings over the life of the product will affect the codewheel performance characteristics depending on the material. The following reliability table shows results of lifetests under varying conditions of temperature and humidity.

Glass Codewheel Tests

Test	Duration	Number of Parts	Number of Failures
Storage at 100°C	1000 hours	44	0
Rotating at 100°C	500 hours	10	0
Temperature Cycle: -40°C to +100°C	500 cycles	98	0
Temperature/Humidity: 85°C/85% R.H.	500 hours	43	0

Film Codewheel Tests

Test	Duration	Number of Parts	Number of Failures
Storage at 70°C	1000 hours	118	0
Rotating at 70°C	500 hours	10	0
Temperature Cycle: -40°C to +70°C	500 cycles	66	0
Temperature Cycle: +20°C to +40°C	1000 cycles	64	0
Temperature Cycle: +20°C to +55°C	1000 cycles	46	0
Temperature Cycle: +20°C to +70°C	500 cycles	50	0

Mounting Rotary Encoders with Codewheels

There are two orientations for mounting the Agilent encoder module and Agilent codewheel. Figure 1a shows mounting the module with side A as the mounting plane. Figure 1b shows mounting the module with side B as the mounting plane. When assembling the encoder and codewheel, it is important to maintain the tolerances of Side A of the module, and the image side of the codewheel. See module Data Sheets for these tolerances.

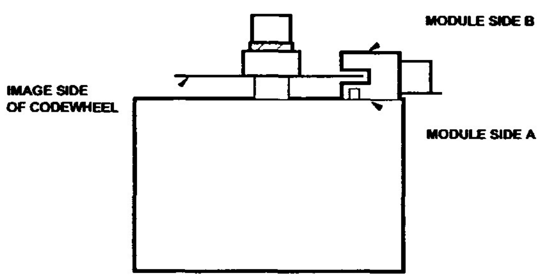


Figure 1a.

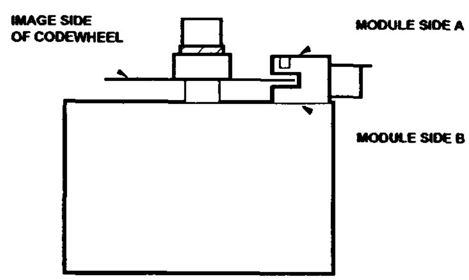


Figure 1b.

*Please note that the image side of the codewheel must always be facing the module Side A.

Mounting with Module Side A as the Mounting Plane

Mounting a high resolution or three channel encoder with Module Side A as the mounting plane requires alignment pins in the motor base. These alignment pins provide the necessary centering of the module with respect to the center of the motor shaft. In addition to centering, the codewheel gap is also important. Please refer to the respective encoder data sheet for necessary mounting information.

Mounting with Module Side B as the Mounting Plane, using Agilent Assembly Tools

Agilent offers centering tools and gap setting tools only for the case when the module is mounted with Side B down. Please refer to the Ordering Information Table to choose the correct assembly tools.

Assembly Instructions Using Agilent Assembly Tools

Instructions

1. Place codewheel on shaft.
2. Set codewheel height:
   (a) Place the correct gap setting tool (per Ordering Information Table) on motor base, flush up against the motor shaft as shown in Figure 2. The shim has two different size steps. Choose the one that most closely matches the width of the codewheel boss. The shim should not contact the codewheel boss.
   (b) Push codewheel down against gap setting shim. The codewheel is now at the proper height.
   (c) Tighten codewheel setscrew.
3. Insert mounting screws through module and thread into the motor base. Do not tighten screws.
4. Slide the HEDS-8905 or HEDS-8906 centering tool over codewheel hub and onto module as shown in Figure 3. The pins of the alignment tool should fit snugly inside the alignment recesses of the module.
5. While holding alignment tool in place, tighten screws down to secure module.
6. Remove alignment tools.

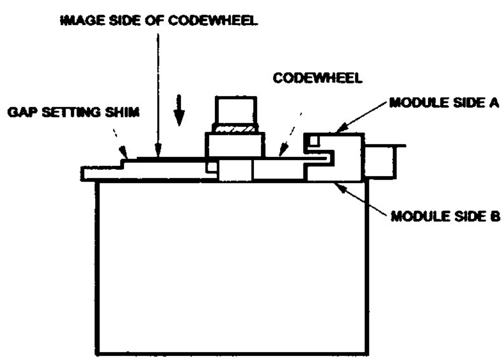


Figure 2. Alignment Tool is Used to Set Height of Codewheel.

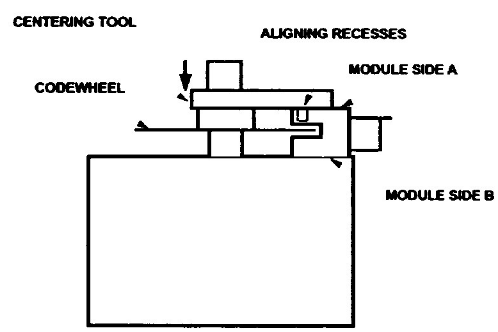


Figure 3. Alignment Tool is Placed over Shaft and onto Codewheel Hub. Alignment Tool Pins Mate with Aligning Recesses on Module.

Mechanical Drawings

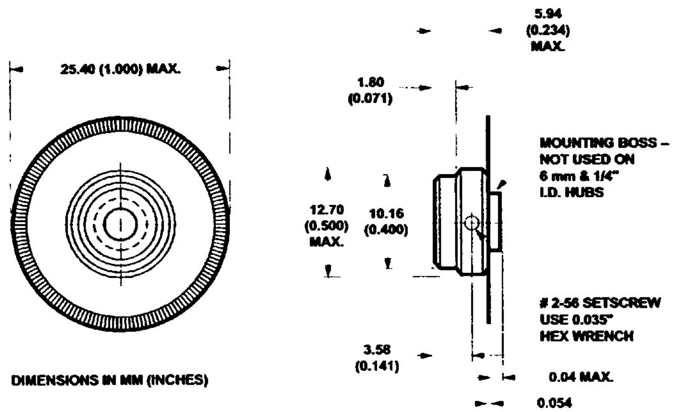


Figure 4. HEDS-5120 Codewheel.

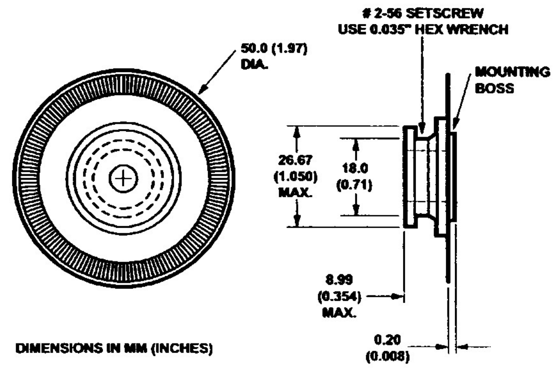


Figure 5. HEDS-6100 Codewheel.

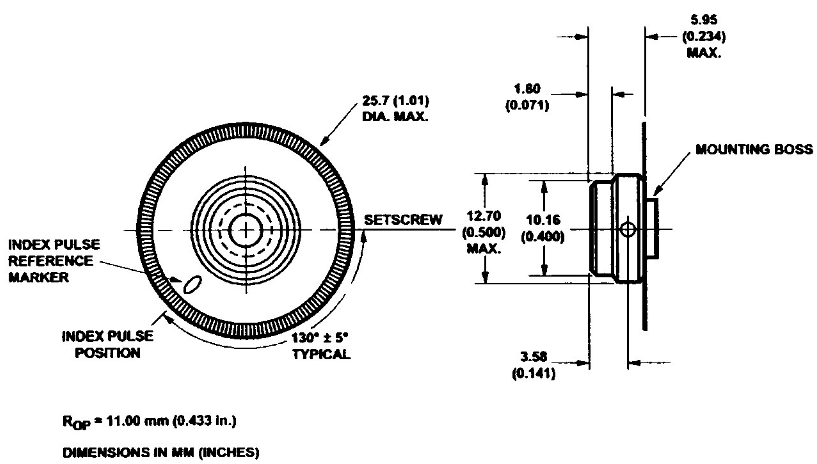


Figure 6. HEDS-5140 Codewheel Used with HEDS-9140.

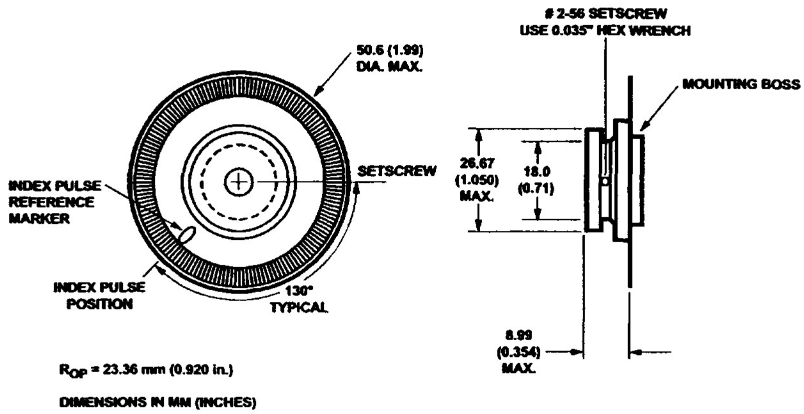


Figure 7. HEDS-6140 Codewheel Used with HEDS-9040.

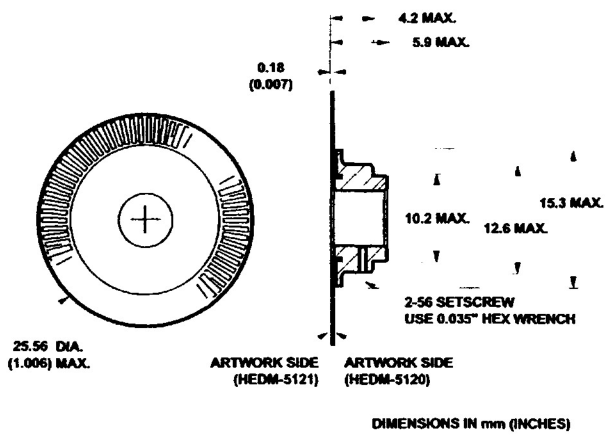


Figure 8. HEDM-5120 Codewheel/HEDM-5121 Codewheel.

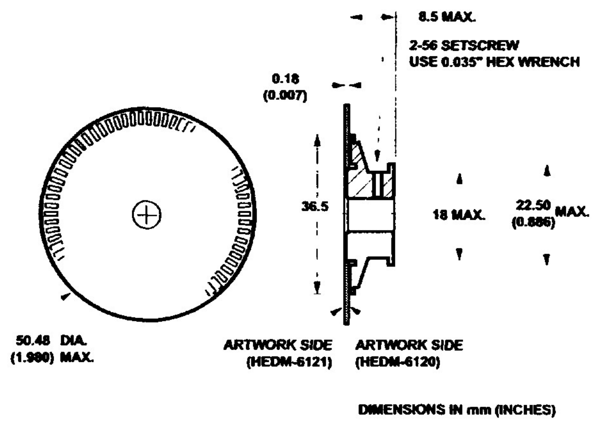


Figure 9. HEDM-6120 Codewheel/HEDM-6121 Codewheel.

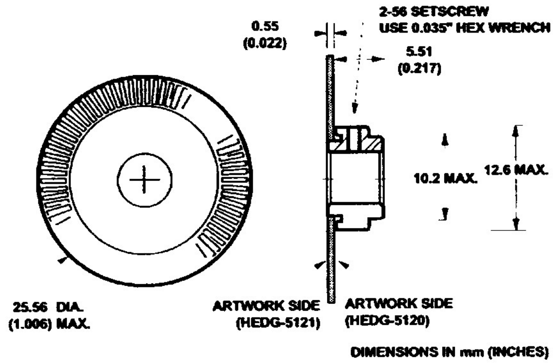


Figure 10. HEDG-5120 Codewheel/HEDG-5121 Codewheel.

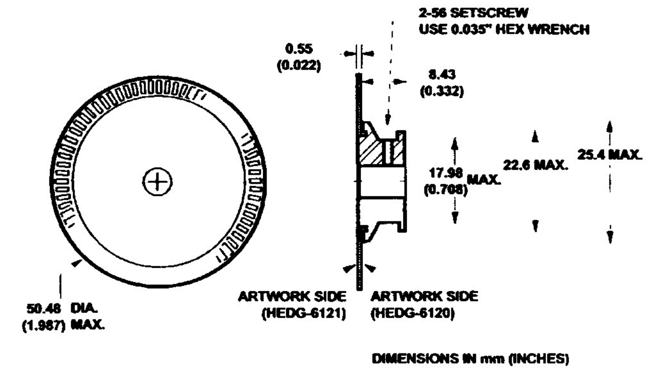


Figure 11. HEDG-6120 Codewheel/HEDG-6121 Codewheel.

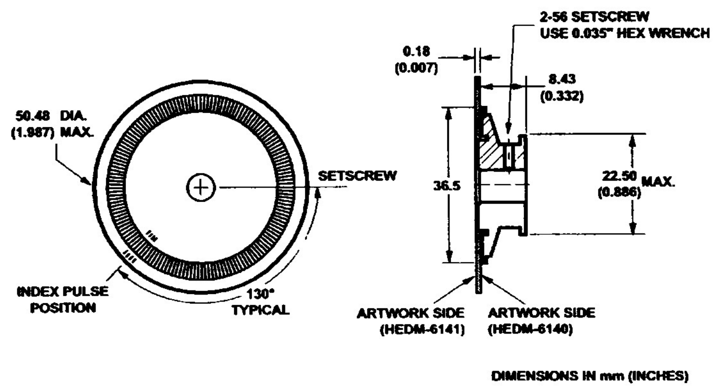


Figure 12. HEDM-6140 Codewheel/HEDM-6141 Codewheel.

Ordering Information Encoder Modules, Codewheel and Assembly Tools

Metal Codewheels

HEDS-9100 option [S] [0] [0] **modules** — **HEDS-5120 codewheels** **Option** [S] [0 6] **Rop = 11 mm, 2 channels**

Resolution (Cycles/Rev)
S - 50 CPR
K - 96 CPR
C - 100 CPR
D - 192 CPR
E - 200 CPR
F - 256 CPR
G - 360 CPR
H - 400 CPR
A - 500 CPR
I - 512 CPR

Shaft Diameter
01 - 2 mm
02 - 3 mm
03 - 1/8 in.
04 - 5/32 in.
05 - 3/16 in.
06 - 1/4 in.
11 - 4 mm
14 - 5 mm
12 - 6 mm
13 - 8 mm

Assembly Tools	
Centering	Gap-Setting
HEDS-8905	HEDS-8901

06F5909
HEDS-9001 # 600
2.805

16F7574
HEDS-5120 # 606
17.24

HEDS-9140 option [ ] [0] [0] **modules** — **HEDS-5140 codewheels** **Option** [ ] [ ] [ ] **Rop = 11 mm, 3 channels**

Resolution (Cycles/Rev)
S - 50 CPR
K - 96 CPR
C - 100 CPR
E - 200 CPR
F - 256 CPR
G - 360 CPR
H - 400 CPR
A - 500 CPR
I - 512 CPR

Shaft Diameter
01 - 2 mm
02 - 3 mm
03 - 1/8 in.
04 - 5/32 in.
05 - 3/16 in.
06 - 1/4 in.
11 - 4 mm
14 - 5 mm
12 - 6 mm
13 - 8 mm

Assembly Tools	
Centering	Gap-Setting
HEDS-8905	HEDS-8905

HEDS-9000 option [ ] [0] [0] **modules** — **HEDS-6100 codewheels** **Option** [ ] [ ] [ ] **Rop = 23 mm, 2 channels**

Resolution (Cycles/Rev)
A - 500 CPR
B - 1000 CPR

Shaft Diameter
05 - 3/16 in.
06 - 1/4 in.
07 - 5/16 in.
08 - 3/8 in.
09 - 1/2 in.
10 - 5/8 in.
11 - 4 mm
12 - 6 mm
13 - 8 mm

Assembly Tools	
Centering	Gap-Setting
HEDS-8906	HEDS-8901

Ordering Information (Cont'd.)

HEDS-9040 option □ 0 0 **modules**

HEDS-6140 codewheels Option □ □□

Rop = 23 mm, 3 channels

Resolution (Cycles/Rev)	Shaft Diameter
B - 1000 CPR	05 - 3/16 in.
J - 1024 CPR	06 - 1/4 in.
	07 - 5/16 in.
	08 - 3/8 in.
	09 - 1/2 in.
	10 - 5/8 in.
	11 - 4 mm
	12 - 6 mm
	13 - 8 mm

Assembly Tools	
Centering	Gap-Setting
HEDS-8906	HEDS-8906

Note:

1. For the lower resolution, two channel encoders, (11 mm ≤ 512 CPR; 23 mm ≤ 1024 CPR) the centering tool and gap-settting shim are not necessary, but sometimes helpful in an assembly process.

Film Codewheels

HEDS-9100 modules option □ 0 0

HEDM-512 □ **codewheels option** □ □□

Rop = 11 mm, 2 channels

Resolution (Cycles/Rev)	Artwork Orientation	Shaft Diameter
B - 1000 CPR	0 - Artwork on hub side (Use when module side B is down)	01 - 2 mm
J - 1024 CPR	1 - Artwork opposite hub side (use when module side A is down)	02 - 3 mm
		03 - 1/8 in.
		04 - 5/32 in.
		05 - 3/16 in.
		06 - 1/4 in.
		11 - 4 mm
		14 - 5 mm
		12 - 6 mm
		13 - 8 mm

Assembly Tools	
Centering	Gap-Setting
HEDS-8905	HEDS-8901

Ordering Information (Cont'd.)

HEDS-9000 modules option □ 0 0

HEDM-612□ **codewheels option** □ □□

Rop = 23 mm, 2 channels

Assembly Tools

Centering	Gap-Setting
HEDS-8906	HEDS-8906

Resolution (Cycles/Rev)
- T - 2000 CPR
- U - 2048 CPR

Artwork Orientation
- 0 - Artwork on hub side (Use when module side B is down)
- 1 - Artwork opposite hub side (use when module side A is down)

Shaft Diameter
- 05 - 3/16 in.
- 06 - 1/4 in.
- 07 - 5/16 in.
- 08 - 3/8 in.
- 09 - 1/2 in.
- 10 - 5/8 in.
- 11 - 4 mm
- 12 - 6 mm
- 13 - 8 mm

HEDS-9040 modules option □ 0 0

HEDM-614□ **codewheels option** □ □□

Rop = 23 mm, 3 channels

Assembly Tools

Centering	Gap-Setting
HEDS-8906	HEDS-8906

Resolution (Cycles/Rev)
- T - 2000 CPR

Artwork Orientation*
- 0 - Artwork on hub side (Use when module side B is down)
- 1 - Artwork opposite hub side (use when module side A is down)

Shaft Diameter
- 05 - 3/16 in.
- 06 - 1/4 in.
- 07 - 5/16 in.
- 08 - 3/8 in.
- 09 - 1/2 in.
- 10 - 5/8 in.
- 11 - 4 mm
- 12 - 6 mm
- 13 - 8 mm

*Index will not work if wrong orientation is used.

Ordering Information (Cont'd.)

Glass Codewheels

HEDS-9100 modules option [ ] [0] [0]

HEDG-512 [ ] codewheels option [ ] [ ] [ ]

Rop = 11 mm, 2 channels

Assembly Tools	
Centering	**Gap-Setting**
HEDS-8905	**HEDS-8932**

Resolution (Cycles/Rev)
B - 1000 CPR
J - 1024 CPR

Artwork Orientation
0 - Artwork on hub side (Use when module side B is down)
1 - Artwork opposite hub side (use when module side A is down)

Shaft Diameter
01 - 2 mm
02 - 3 mm
03 - 1/8 in.
04 - 5/32 in.
05 - 3/16 in.
06 - 1/4 in.
11 - 4 mm
14 - 5 mm
12 - 6 mm
13 - 8 mm

HEDS-9000 modules option [ ] [0] [0]

HEDG-612 [ ] codewheels option [ ] [ ] [ ]

Rop = 23 mm, 2 channels

Assembly Tools	
Centering	**Gap-Setting**
HEDS-8906	**HEDS-8932**

Resolution (Cycles/Rev)
T - 2000 CPR
U - 2048 CPR

Artwork Orientation
0 - Artwork on hub side (Use when module side B is down)
1 - Artwork opposite hub side (use when module side A is down)

Shaft Diameter
05 - 3/16 in.
06 - 1/4 in.
07 - 5/16 in.
08 - 3/8 in.
09 - 1/2 in.
10 - 5/8 in.
11 - 4 mm
12 - 6 mm
13 - 8 mm

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Data subject to change.

Obsoletes 5964-6127E (1/96)

5965-5891E (11/99)

National Semiconductor

June 2000

LM2907/LM2917 Frequency to Voltage Converter

General Description

The LM2907, LM2917 series are monolithic frequency to voltage converters with a high gain op amp/comparator designed to operate a relay, lamp, or other load when the input frequency reaches or exceeds a selected rate. The tachometer uses a charge pump technique and offers frequency doubling for low ripple, full input protection in two versions (LM2907-8, LM2917-8) and its output swings to ground for a zero frequency input.

The op amp/comparator is fully compatible with the tachometer and has a floating transistor as its output. This feature allows either a ground or supply referred load of up to 50 mA. The collector may be taken above V_{CC} up to a maximum V_{CE} of 28V.

The two basic configurations offered include an 8-pin device with a *ground referenced tachometer* input and an internal connection between the tachometer output and the op amp non-inverting input. This version is well suited for single speed or frequency switching or fully buffered frequency to voltage conversion applications.

The more versatile configurations provide differential tachometer input and uncommitted op amp inputs. With this version the tachometer input may be floated and the op amp becomes suitable for active filter conditioning of the tachometer output.

Both of these configurations are available with an active shunt regulator connected across the power leads. The regulator clamps the supply such that stable frequency to voltage and frequency to current operations are possible with any supply voltage and a suitable resistor.

Advantages

- Output swings to ground for zero frequency input
- Easy to use; $V_{OUT} = f_{IN} \times V_{CC} \times R1 \times C1$
- Only one RC network provides frequency doubling
- Zener regulator on chip allows accurate and stable frequency to voltage or current conversion (LM2917)

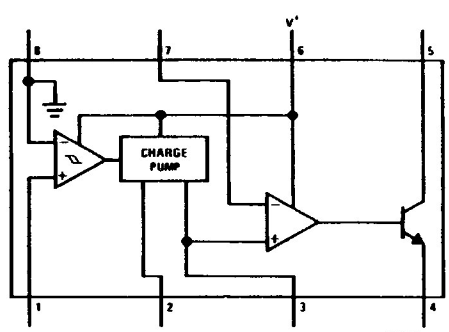
Features

- Ground referenced tachometer input interfaces directly with variable reluctance magnetic pickups
- Op amp/comparator has floating transistor output
- 50 mA sink or source to operate relays, solenoids, meters, or LEDs
- Frequency doubling for low ripple
- Tachometer has built-in hysteresis with either differential input or ground referenced input
- Built-in zener on LM2917
- ±0.3% linearity typical
- Ground referenced tachometer is fully protected from damage due to swings above V_{CC} and below ground

Applications

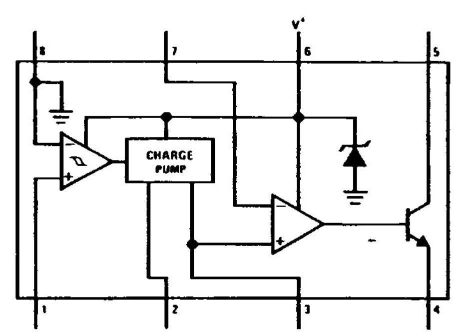
- Over/under speed sensing
- Frequency to voltage conversion (tachometer)
- Speedometers
- Breaker point dwell meters
- Hand-held tachometer
- Speed governors
- Cruise control
- Automotive door lock control
- Clutch control
- Horn control
- Touch or sound switches

Block and Connection Diagrams Dual-In-Line and Small Outline Packages, Top Views



DS007942-1

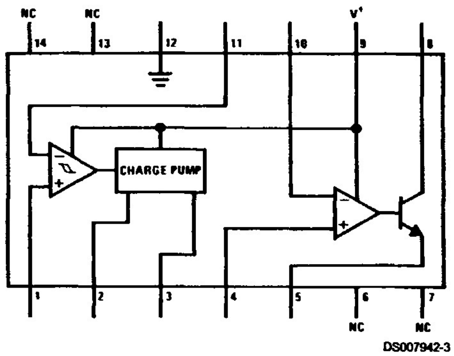
Order Number LM2907M-8 or LM2907N-8
See NS Package Number M08A or N08E



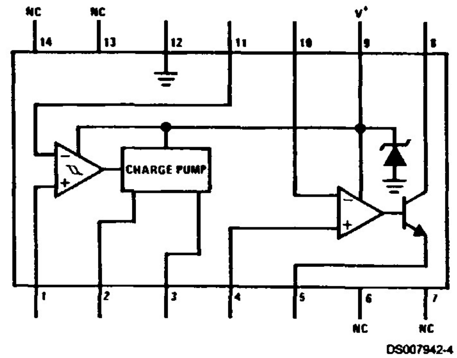
DS007942-2

Order Number LM2917M-8 or LM2917N-8
See NS Package Number M08A or N08E

Block and Connection Diagrams Dual-In-Line and Small Outline Packages, Top Views (Continued)



Order Number LM2907M or LM2907N
See NS Package Number M14A or N14A



Order Number LM2917M or LM2917N
See NS Package Number M14A or N14A

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Supply Voltage	28V
Supply Current (Zener Options)	25 mA
Collector Voltage	28V
Differential Input Voltage	
Tachometer	28V
Op Amp/Comparator	28V
Input Voltage Range	
Tachometer	
LM2907-8, LM2917-8	±28V
LM2907, LM2917	0.0V to +28V
Op Amp/Comparator	0.0V to +28V
Power Dissipation	
LM2907-8, LM2917-8	1200 mW
LM2907-14, LM2917-14	1580 mW
See (Note 1)	
Operating Temperature Range	−40°C to +85°C
Storage Temperature Range	−65°C to +150°C
Soldering Information	
Dual-In-Line Package	
Soldering (10 seconds)	260°C
Small Outline Package	
Vapor Phase (60 seconds)	215°C
Infrared (15 seconds)	220°C

See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" for other methods of soldering surface mount devices.

Electrical Characteristics

V_{CC} = 12 V_{DC}, T_A = 25°C, see test circuit

Symbol	Parameter	Conditions	Min	Typ	Max	Units
TACHOMETER						
	Input Thresholds	V_{IN} = 250 mVp-p @ 1 kHz (Note 2)	±10	±25	±40	mV
	Hysteresis	V_{IN} = 250 mVp-p @ 1 kHz (Note 2)		30		mV
	Offset Voltage	V_{IN} = 250 mVp-p @ 1 kHz (Note 2)				
	LM2907/LM2917			3.5	10	mV
	LM2907-8/LM2917-8			5	15	mV
	Input Bias Current	V_{IN} = ±50 mV_{DC}		0.1	1	µA
V_{OH}	Pin 2	V_{IN} = +125 mV_{DC} (Note 3)		8.3		V
V_{OL}	Pin 2	V_{IN} = −125 mV_{DC} (Note 3)		2.3		V
I_2, I_3	Output Current	V2 = V3 = 6.0V (Note 4)	140	180	240	µA
I_3	Leakage Current	I2 = 0, V3 = 0			0.1	µA
K	Gain Constant	(Note 3)	0.9	1.0	1.1	
	Linearity	f_{IN} = 1 kHz, 5 kHz, 10 kHz (Note 5)	−1.0	0.3	+1.0	%
OP/AMP COMPARATOR						
V_{OS}		V_{IN} = 6.0V		3	10	mV
I_{BIAS}		V_{IN} = 6.0V		50	500	nA
	Input Common-Mode Voltage		0		V_{CC}−1.5V	V
	Voltage Gain			200		V/mV
	Output Sink Current	V_C = 1.0	40	50		mA
	Output Source Current	V_E = V_{CC} −2.0		10		mA
	Saturation Voltage	I_{SINK} = 5 mA		0.1	0.5	V
		I_{SINK} = 20 mA			1.0	V
		I_{SINK} = 50 mA		1.0	1.5	V
ZENER REGULATOR						
	Regulator Voltage	R_{DROP} = 470Ω		7.56		V
	Series Resistance			10.5	15	Ω
	Temperature Stability			+1		mV/°C
	TOTAL SUPPLY CURRENT			3.8	6	mA

Note 1: For operation in ambient temperatures above 25°C, the device must be derated based on a 150°C maximum junction temperature and a thermal resistance of 101°C/W junction to ambient for LM2907-8 and LM2917-8, and 79°C/W junction to ambient for LM2907-14 and LM2917-14.

Note 2: Hysteresis is the sum $+V_{TH} - (-V_{TH})$, offset voltage is their difference. See test circuit.

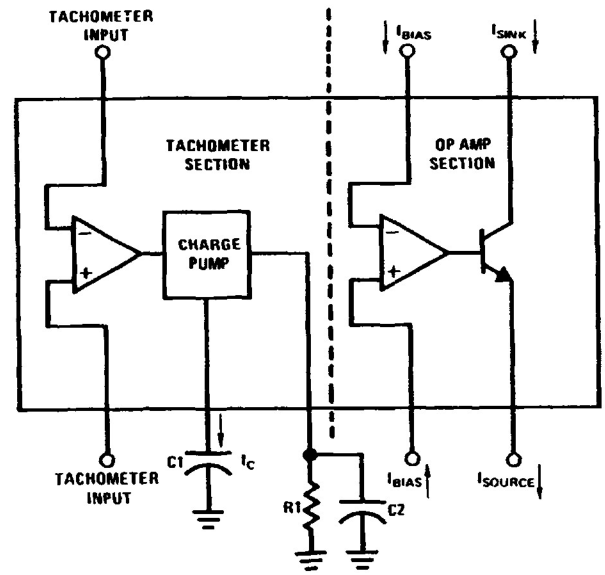
Note 3: V_{OH} is equal to ¾ x V_{CC} − 1 V_{BE}, V_{OL} is equal to ¼ x V_{CC} − 1 V_{BE} therefore $V_{OH} - V_{OL} = V_{CC}/2$. The difference, $V_{OH} - V_{OL}$, and the mirror gain, I_2/I_3, are the two factors that cause the tachometer gain constant to vary from 1.0.

Note 4: Be sure when choosing the time constant R1 x C1 that R1 is such that the maximum anticipated output voltage at pin 3 can be reached with I_3 x R1 The maximum value for R1 is limited by the output resistance of pin 3 which is greater than 10 MΩ typically

Electrical Characteristics (Continued)

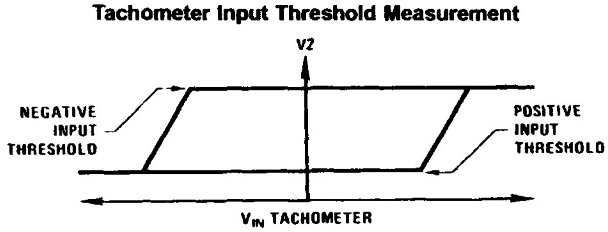
Note 5: Nonlinearity is defined as the deviation of V_{OUT} (@ pin 3) for f_{IN} = 5 kHz from a straight line defined by the V_{OUT} @ 1 kHz and V_{OUT} @ 10 kHz. C1 = 1000 pF, R1 = 68k and C2 = 0.22 mFd.

Test Circuit and Waveform



DS007942-6

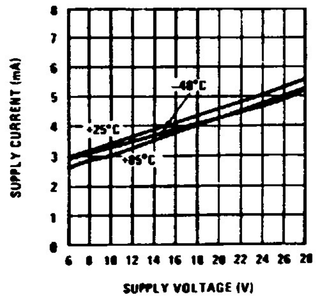
Tachometer Input Threshold Measurement



DS007942-7

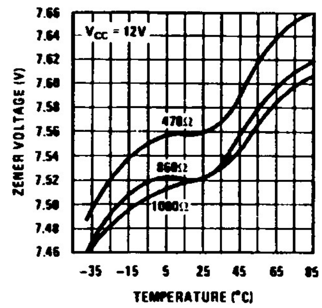
Typical Performance Characteristics

Total Supply Current



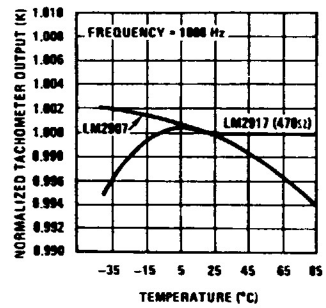
DS007942-40

Zener Voltage vs Temperature



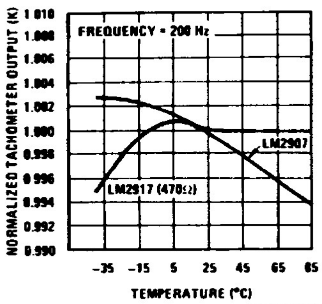
DS007942-41

Normalized Tachometer Output vs Temperature



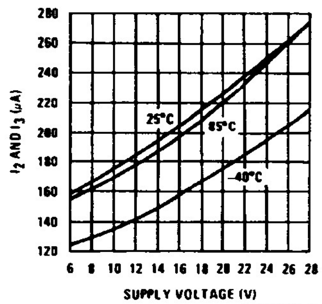
DS007942-42

Normalized Tachometer Output vs Temperature



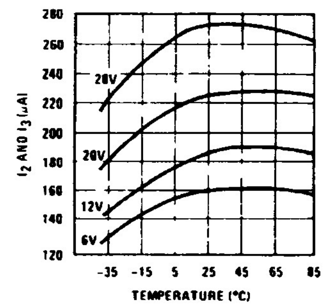
DS007942-43

Tachometer Currents I_2 and I_3 vs Supply Voltage



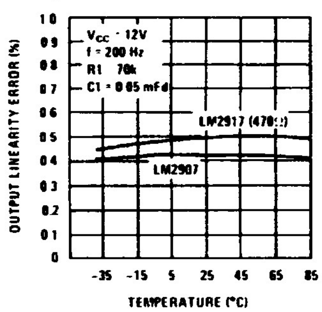
DS007942-44

Tachometer Currents I_2 and I_3 vs Temperature



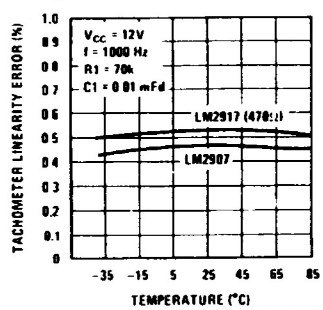
DS007942-45

Tachometer Linearity vs Temperature



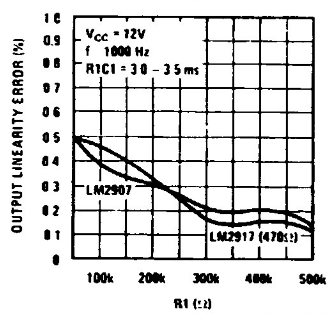
DS007942-46

Tachometer Linearity vs Temperature



DS007942-47

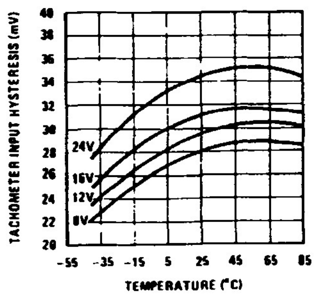
Tachometer Linearity vs R1



DS007942-48

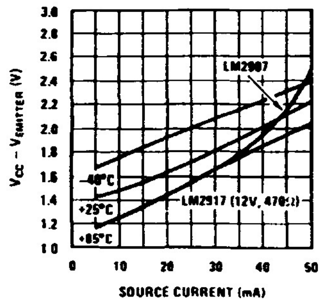
Typical Performance Characteristics (Continued)

Tachometer Input Hysteresis vs Temperature



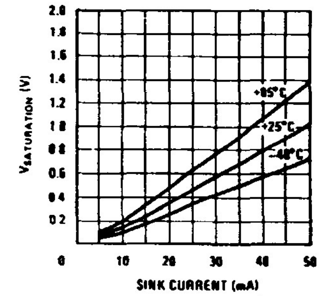
DS007942-49

Op Amp Output Transistor Characteristics



DS007942-50

Op Amp Output Transistor Characteristics



DS007942-51

Applications Information

The LM2907 series of tachometer circuits is designed for minimum external part count applications and maximum versatility. In order to fully exploit its features and advantages let's examine its theory of operation. The first stage of operation is a differential amplifier driving a positive feedback flip-flop circuit. The input threshold voltage is the amount of differential input voltage at which the output of this stage changes state. Two options (LM2907-8, LM2917-8) have one input internally grounded so that an input signal must swing above and below ground and exceed the input thresholds to produce an output. This is offered specifically for magnetic variable reluctance pickups which typically provide a single-ended ac output. This single input is also fully protected against voltage swings to ±28V, which are easily attained with these types of pickups.

The differential input options (LM2907, LM2917) give the user the option of setting his own input switching level and still have the hysteresis around that level for excellent noise rejection in any application. Of course in order to allow the inputs to attain common-mode voltages above ground, input protection is removed and neither input should be taken outside the limits of the supply voltage being used. It is very important that an input not go below ground without some resistance in its lead to limit the current that will then flow in the epi-substrate diode.

Following the input stage is the charge pump where the input frequency is converted to a dc voltage. To do this requires one timing capacitor, one output resistor, and an integrating or filter capacitor. When the input stage changes state (due to a suitable zero crossing or differential voltage on the input) the timing capacitor is either charged or discharged linearly between two voltages whose difference is $V_{CC}/2$. Then in one half cycle of the input frequency or a time equal to 1/2 f_{IN} the change in charge on the timing capacitor is equal to $V_{CC}/2 \times C1$. The average amount of current pumped into or out of the capacitor then is:

$$\frac{\Delta Q}{T} = i_{c(AVG)} = C1 \times \frac{V_{CC}}{2} \times (2f_{IN}) = V_{CC} \times f_{IN} \times C1$$

The output circuit mirrors this current very accurately into the load resistor R1, connected to ground, such that if the pulses of current are integrated with a filter capacitor, then $V_O = i_c \times R1$, and the total conversion equation becomes:

$$V_O = V_{CC} \times f_{IN} \times C1 \times R1 \times K$$

Where K is the gain constant—typically 1.0.

The size of C2 is dependent only on the amount of ripple voltage allowable and the required response time.

CHOOSING R1 AND C1

There are some limitations on the choice of R1 and C1 which should be considered for optimum performance. The timing capacitor also provides internal compensation for the charge pump and should be kept larger than 500 pF for very accurate operation. Smaller values can cause an error current on R1, especially at low temperatures. Several considerations must be met when choosing R1. The output current at pin 3 is internally fixed and therefore $V_O/R1$ must be less than or equal to this value. If R1 is too large, it can become a significant fraction of the output impedance at pin 3 which degrades linearity. Also output ripple voltage must be considered and the size of C2 is affected by R1. An expression that describes the ripple content on pin 3 for a single R1C2 combination is:

$$V_{RIPPLE} = \frac{V_{CC}}{2} \times \frac{C1}{C2} \times \left(1 - \frac{V_{CC} \times f_{IN} \times C1}{I_2}\right) \text{pk-pk}$$

It appears R1 can be chosen independent of ripple, however response time, or the time it takes V_{OUT} to stabilize at a new voltage increases as the size of C2 increases, so a compromise between ripple, response time, and linearity must be chosen carefully.

As a final consideration, the maximum attainable input frequency is determined by V_{CC}, C1 and I_2:

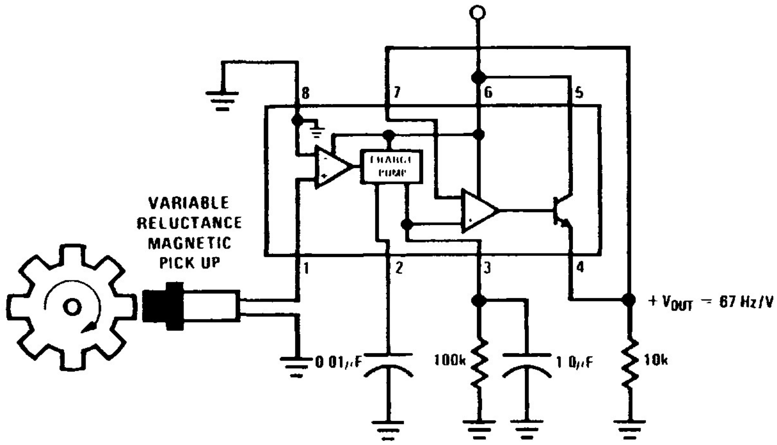
$$f_{MAX} = \frac{I_2}{C1 \times V_{CC}}$$

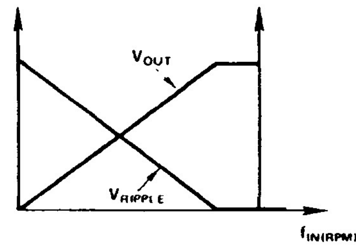
USING ZENER REGULATED OPTIONS (LM2917)

For those applications where an output voltage or current must be obtained independent of supply voltage variations, the LM2917 is offered. The most important consideration in choosing a dropping resistor from the unregulated supply to the device is that the tachometer and op amp circuitry alone require about 3 mA at the voltage level provided by the zener. At low supply voltages there must be some current flowing in the resistor above the 3 mA circuit current to operate the regulator. As an example, if the raw supply varies from 9V to 16V, a resistance of 470Ω will minimize the zener voltage variation to 160 mV. If the resistance goes under 400Ω or over 600Ω the zener variation quickly rises above 200 mV for the same input variation.

Typical Applications

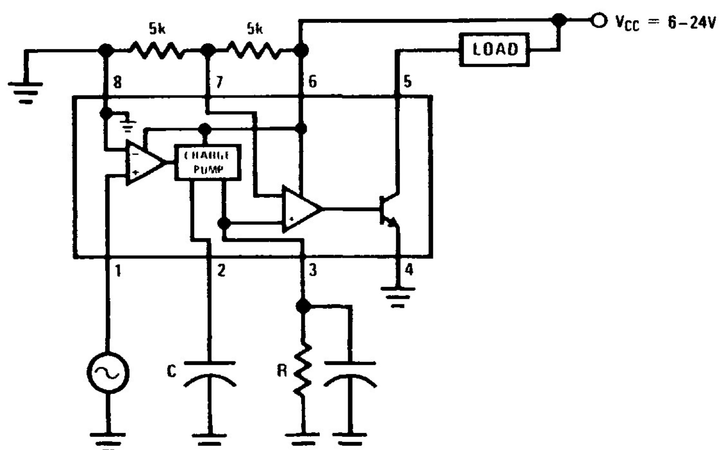
Minimum Component Tachometer





DS007942-8

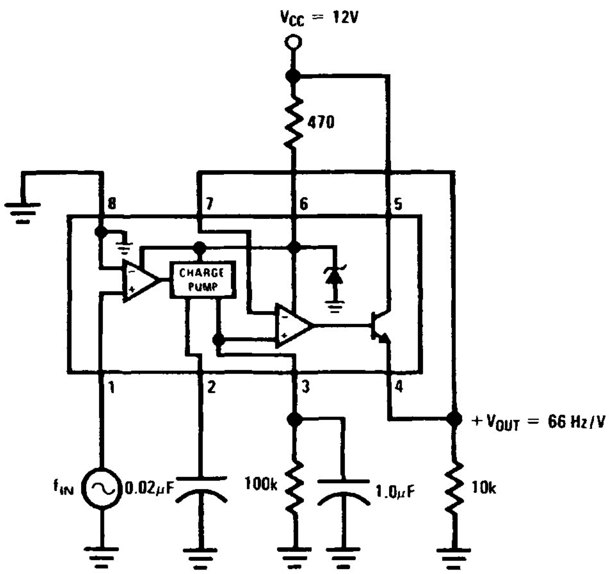
"Speed Switch" Load is Energized When $f_{IN} \geq \frac{1}{2RC}$



DS007942-9

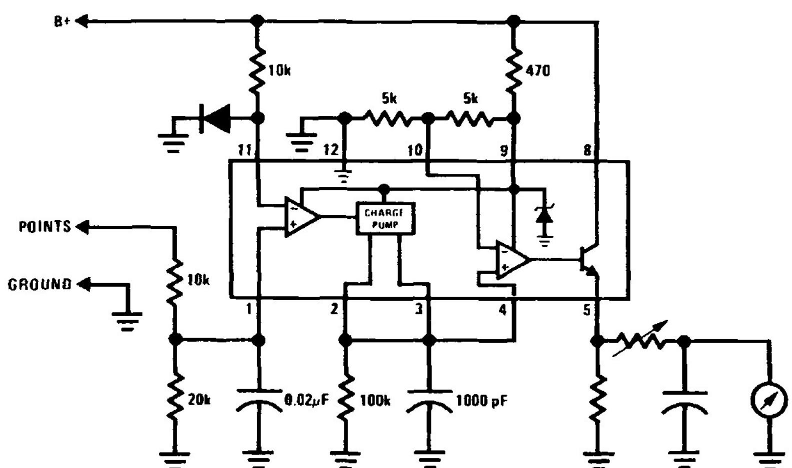
Typical Applications (Continued)

Zener Regulated Frequency to Voltage Converter



DS007942-10

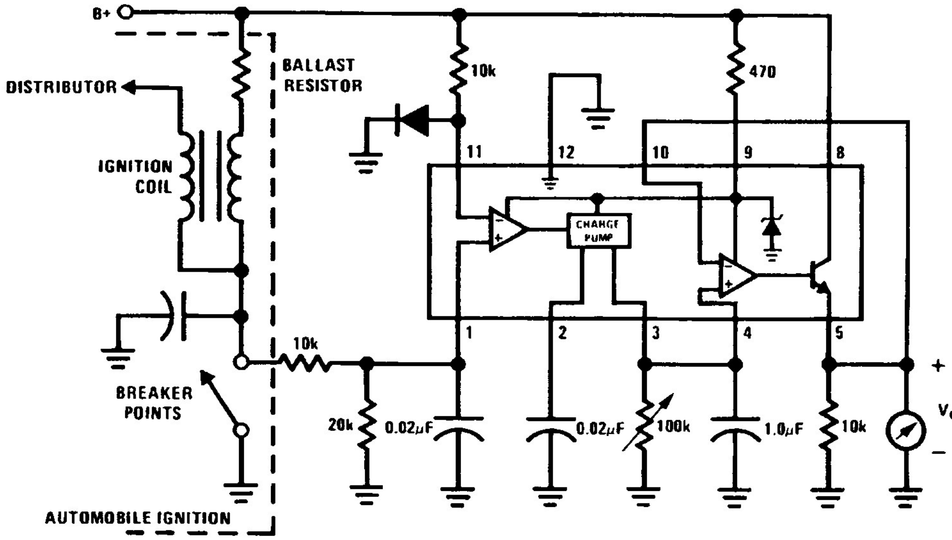
Breaker Point Dwell Meter



DS007942-11

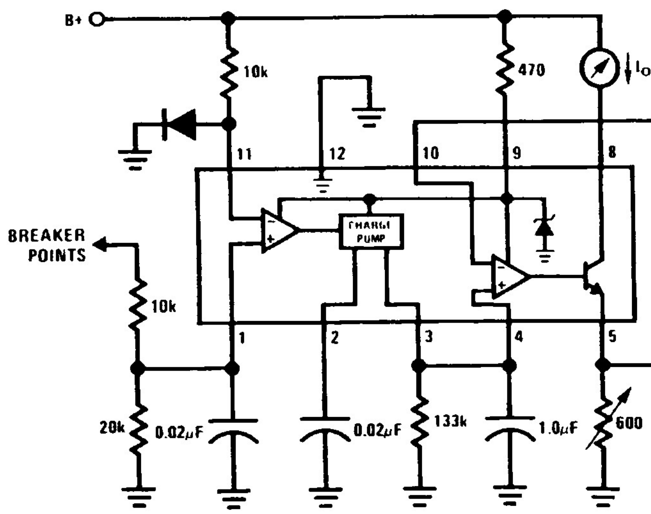
Typical Applications (Continued)

Voltage Driven Meter Indicating Engine RPM
V_O = 6V @ 400 Hz or 6000 ERPM (8 Cylinder Engine)



DS007942-12

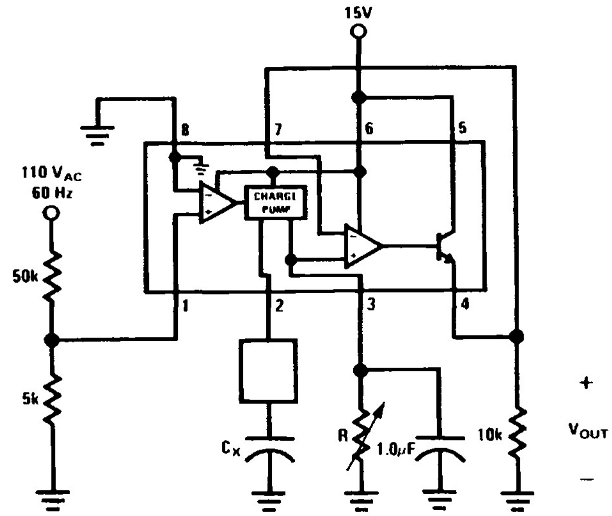
Current Driven Meter Indicating Engine RPM
I_O = 10 mA @ 300 Hz or 6000 ERPM (6 Cylinder Engine)



DS007942-13

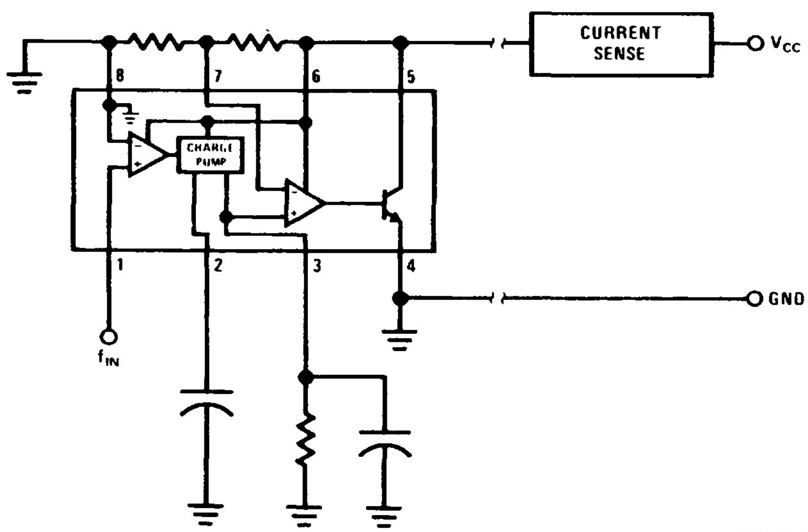
Typical Applications (Continued)

Capacitance Meter
V_{OUT} = 1V–10V for C_X = 0.01 to 0.1 mFd
(R = 111k)



DS007942-14

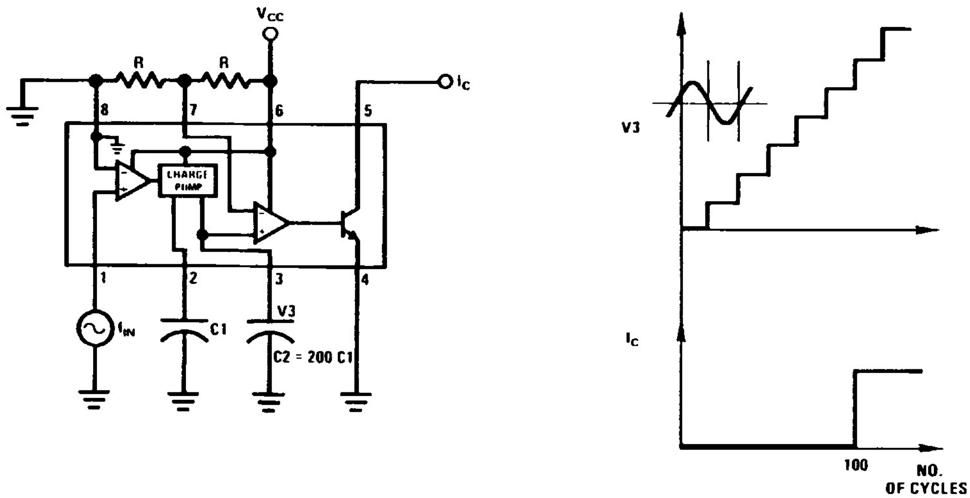
Two-Wire Remote Speed Switch



DS007942-15

Typical Applications (Continued)

100 Cycle Delay Switch



DS007942-16

V3 steps up in voltage by the amount $\frac{V_{CC} \times C1}{C2}$

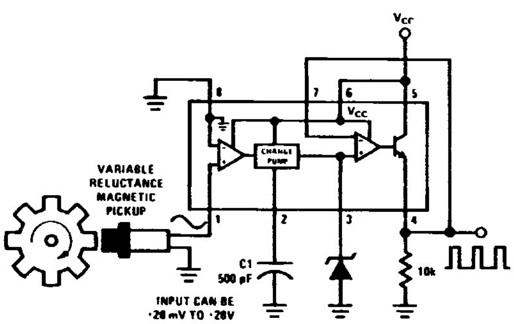
for each complete input cycle (2 zero crossings)

Example:

if C2 = 200 C1 after 100 consecutive input cycles.

V3 = 1/2 V_{CC}

Variable Reluctance Magnetic Pickup Buffer Circuits

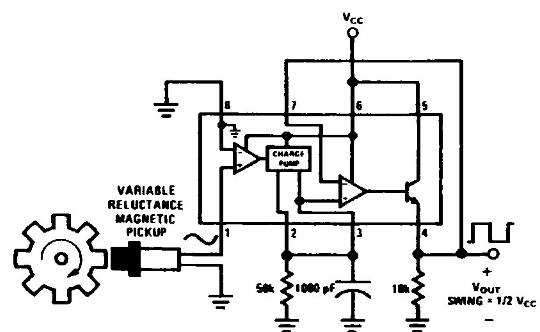


DS007942-39

Precision two-shot output frequency equals twice input frequency.

$$\text{Pulse width} = \frac{V_{CC}}{2}\,\frac{C1}{I2}$$

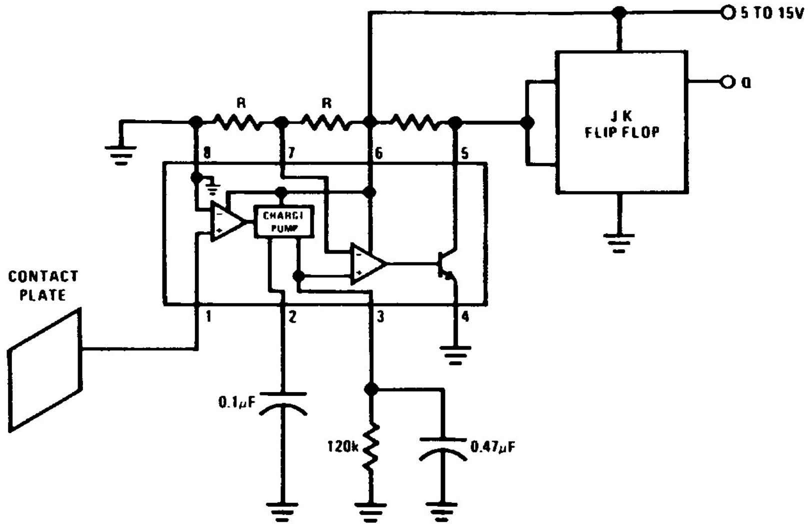
Pulse height = V_{ZENER}



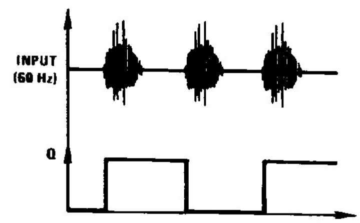
DS007942-17

Typical Applications (Continued)

Finger Touch or Contact Switch

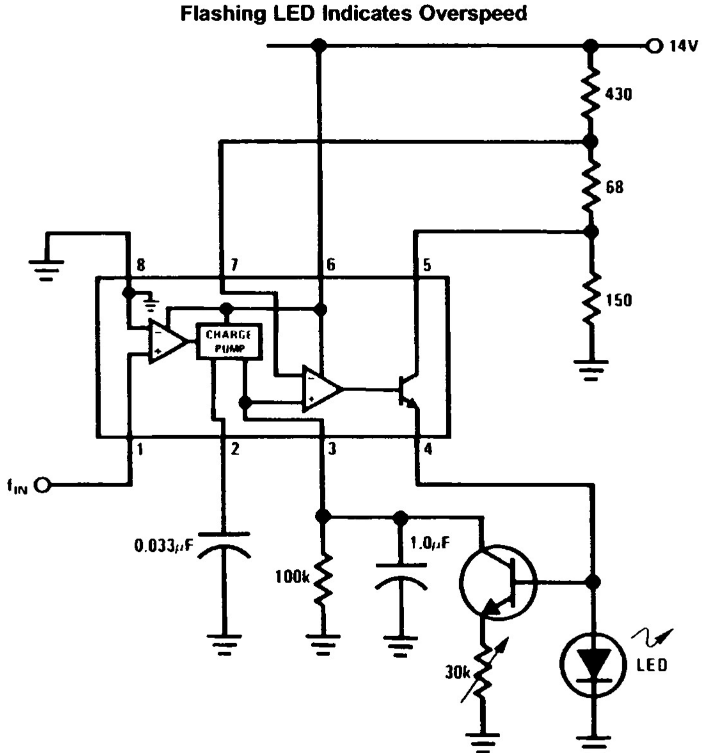


DS007942-18



DS007942-19

Flashing LED Indicates Overspeed

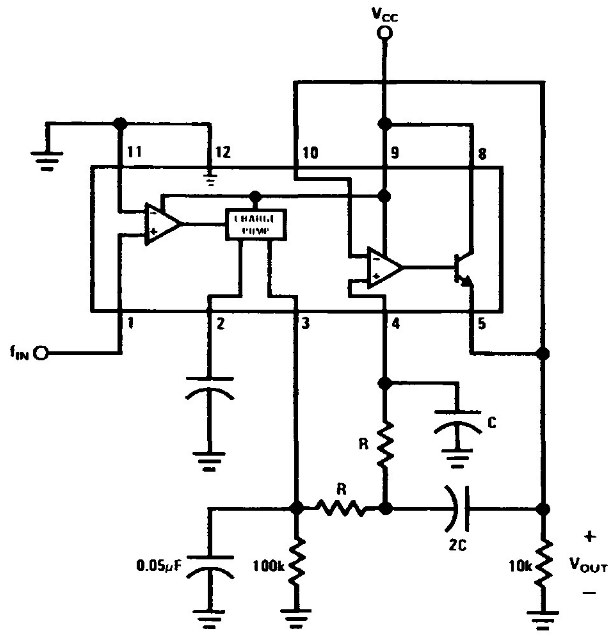


DS007942-20

Flashing begins when $f_{IN} \geq 100$ Hz.
Flash rate increases with input frequency
increase beyond trip point.

Typical Applications (Continued)

Frequency to Voltage Converter with 2 Pole Butterworth Filter to Reduce Ripple

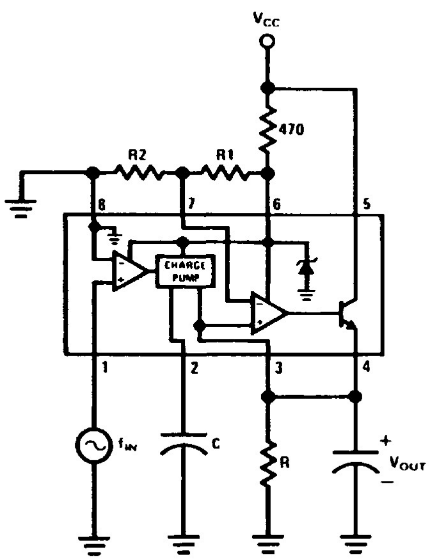


DS007942-21

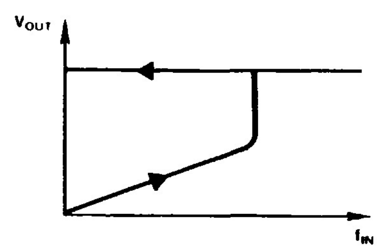
$$f_{POLE} = \frac{0.707}{2\pi RC}$$

$$\tau_{RESPONSE} = \frac{2.57}{2\pi f_{POLE}}$$

Overspeed Latch



DS007942-22



DS007942-23

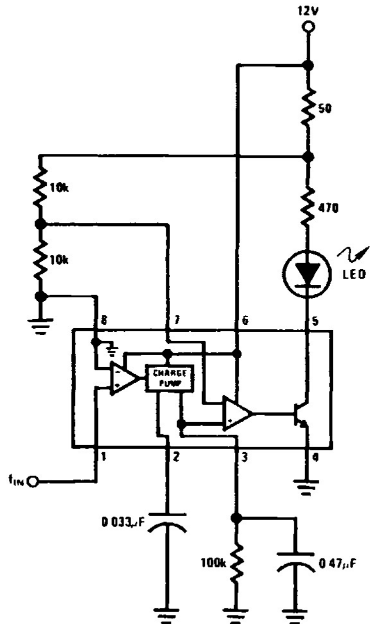
Output latches when

$$f_{IN} = \frac{R2}{R1 + R2}\frac{1}{RC}$$

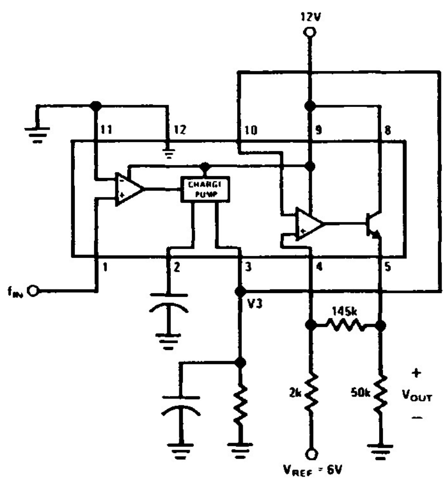
Reset by removing V_{CC}.

Typical Applications (Continued)

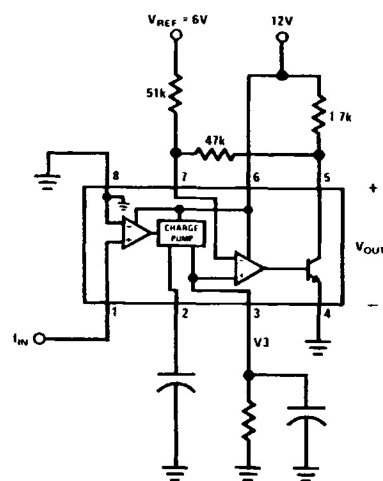
Some Frequency Switch Applications May Require Hysteresis in the Comparator Function Which can be Implemented in Several Ways:



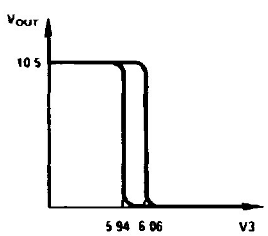
DS007942-24



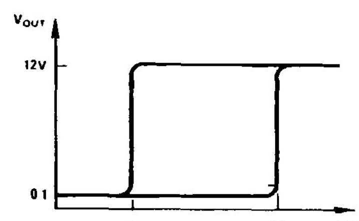
DS007942-25



DS007942-26



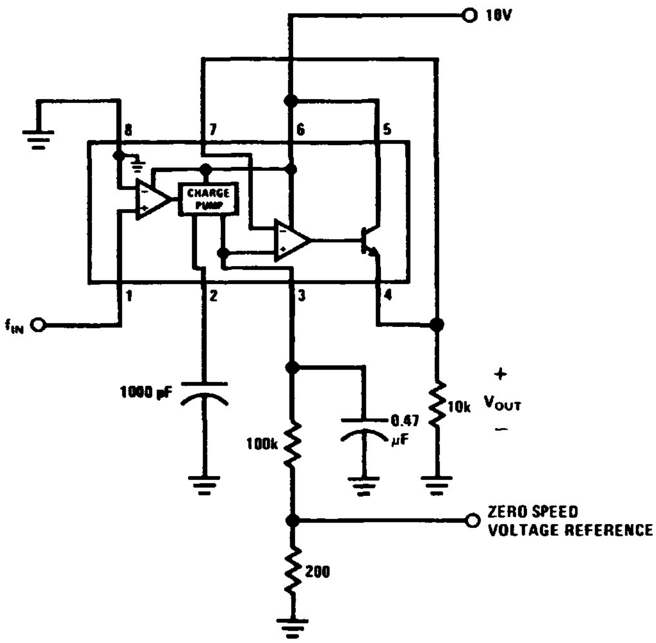
DS007942-27



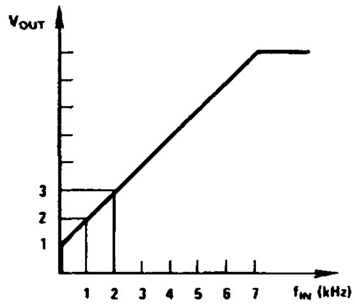
DS007942-28

Typical Applications (Continued)

Changing the Output Voltage for an Input Frequency of Zero

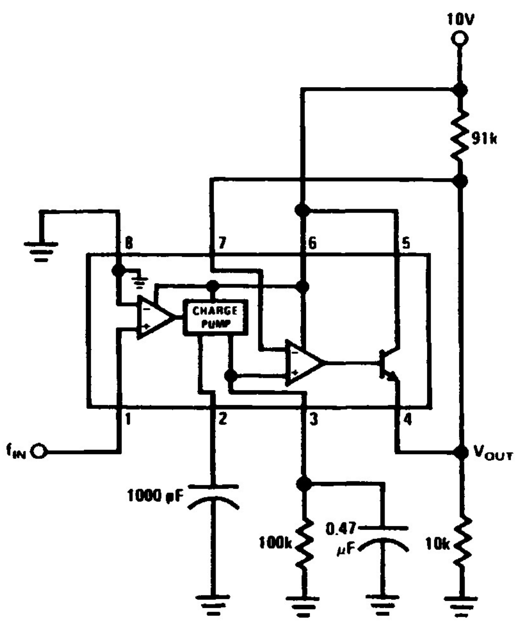


DS007942-29

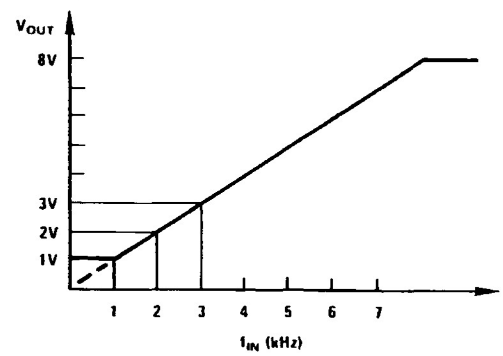


DS007942-30

Changing Tachometer Gain Curve or Clamping the Minimum Output Voltage



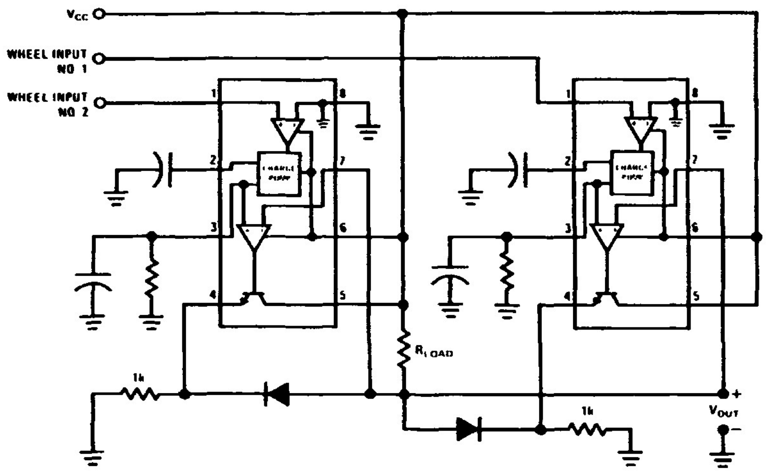
DS007942-31



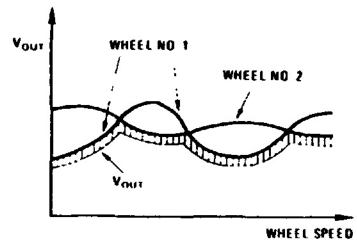
DS007942-32

Anti-Skid Circuit Functions

"Select-Low" Circuit



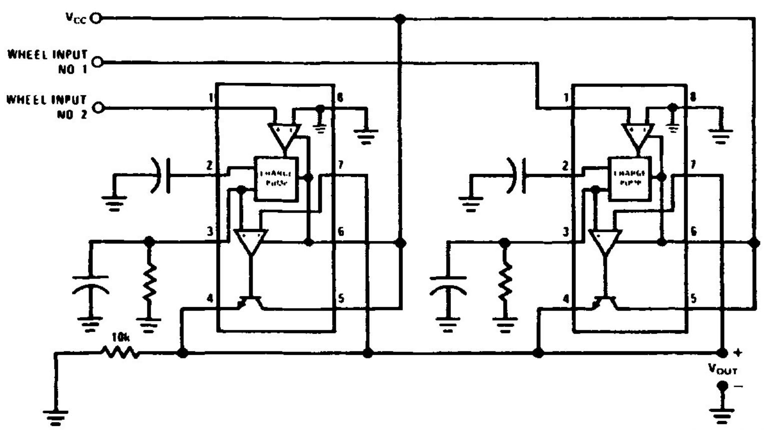
DS007942-33



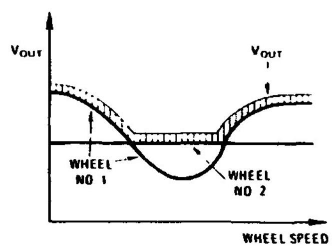
DS007942-34

V_{OUT} is proportional to the lower of the two input wheel speeds.

"Select-High" Circuit



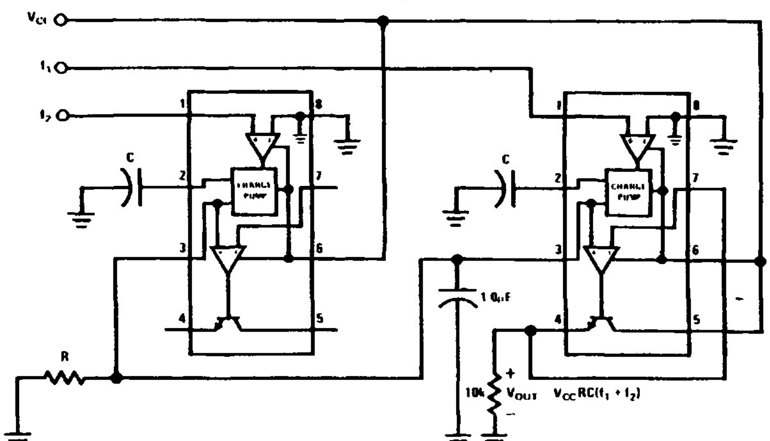
DS007942-35



DS007942-36

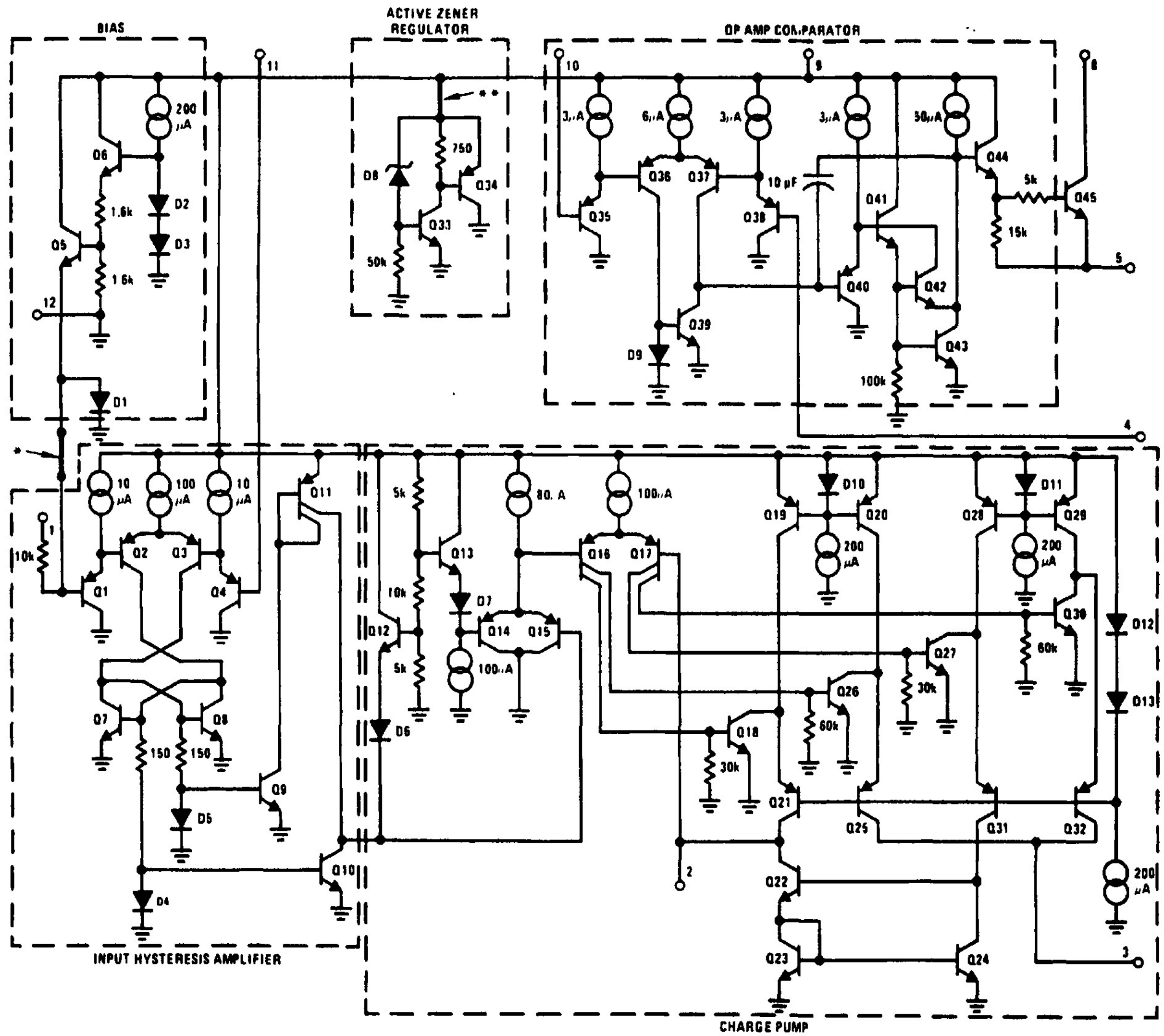
V_{OUT} is proportional to the higher of the two input wheel speeds.

"Select-Average" Circuit



DS007942-37

Equivalent Schematic Diagram

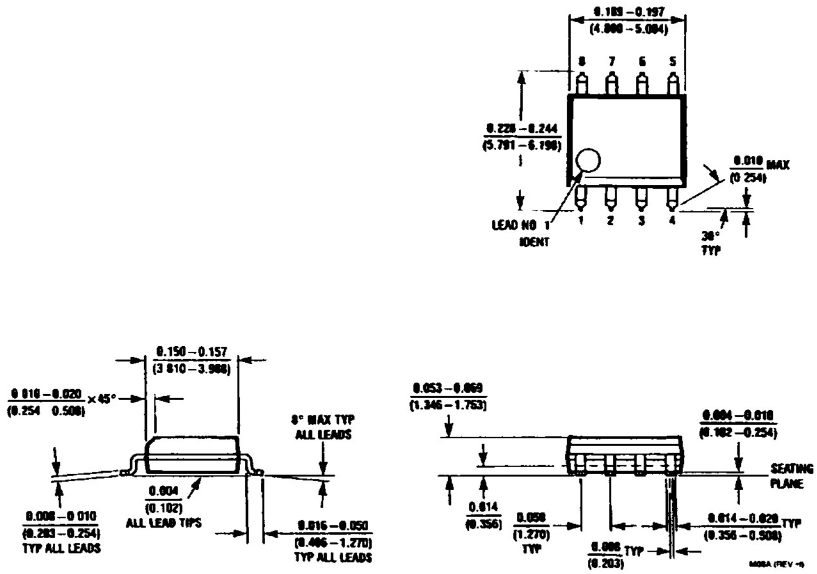


DS007942-38

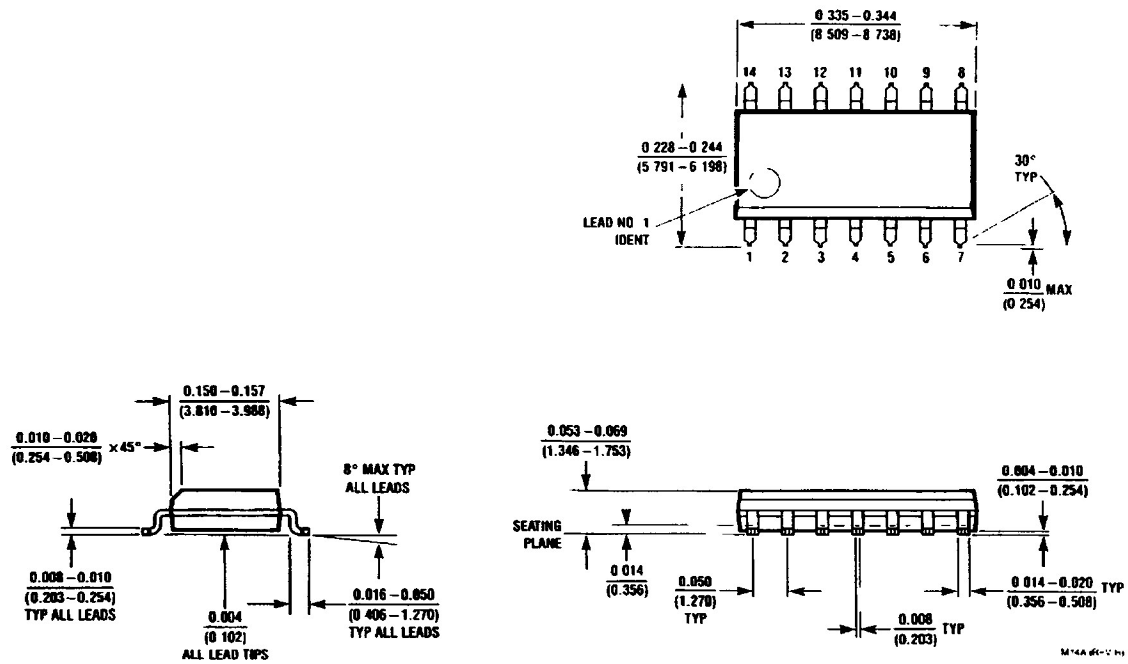
*This connection made on LM2907-8 and LM2917-8 only.

**This connection made on LM2917 and LM2917-8 only.

Physical Dimensions inches (millimeters) unless otherwise noted

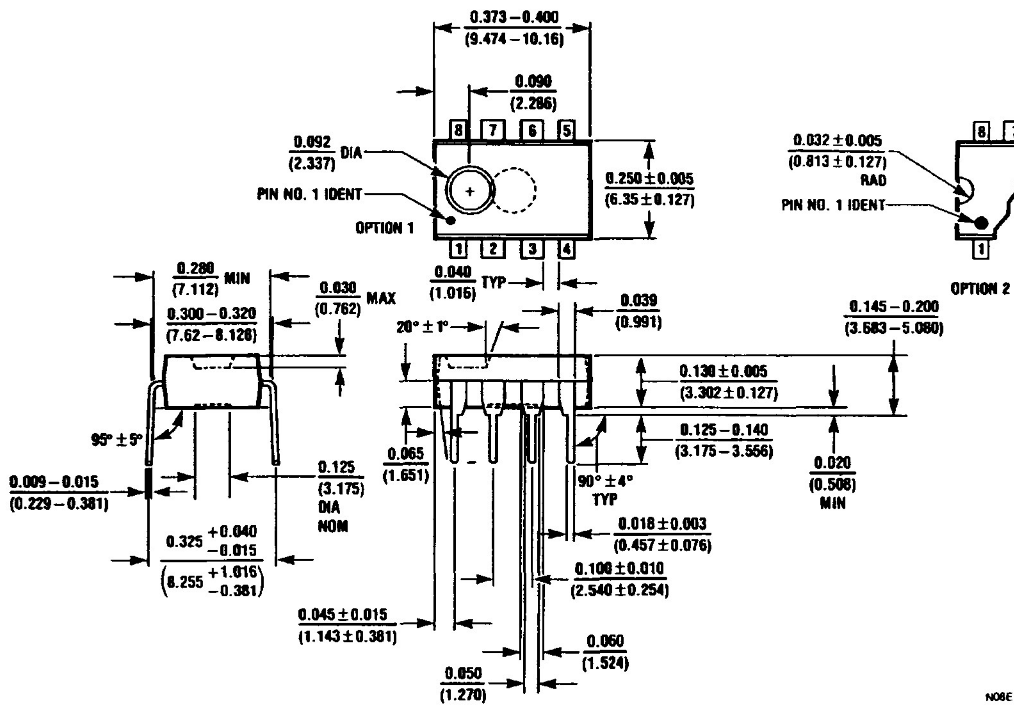


8-Lead (0.150" Wide) Molded Small Outline Package, JEDEC
Order Number LM2907M-8 or LM2917M-8
NS Package Number M08A

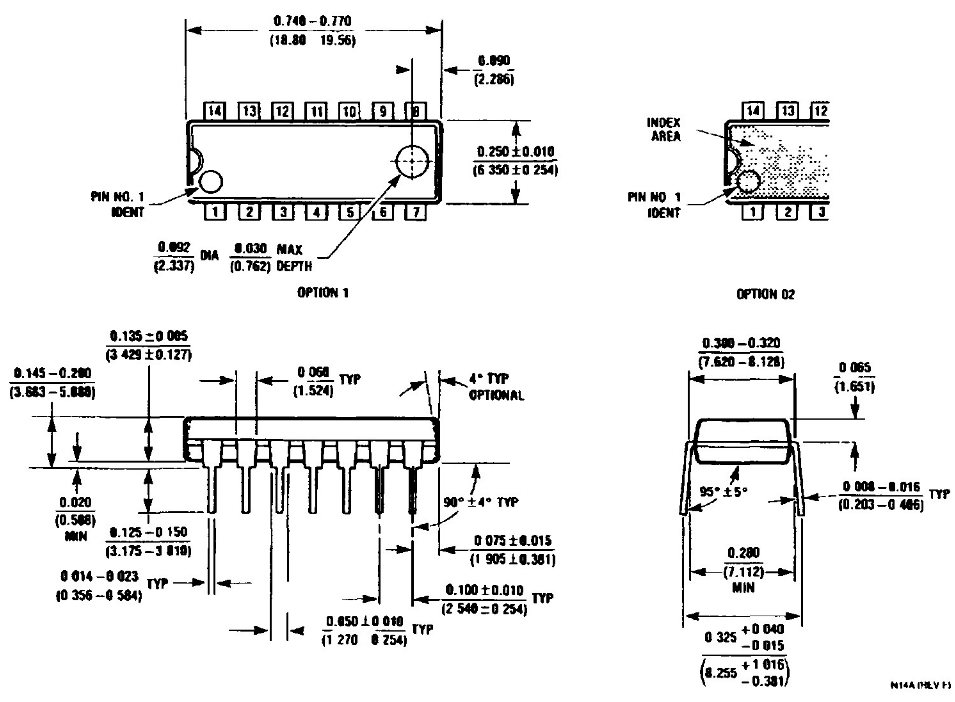


Molded SO Package (M)
Order Number LM2907M or LM2917M
NS Package Number M14A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



Molded Dual-In-Line Package (N)
Order Number LM2907N-8 or LM2917N-8
NS Package Number N08E



Molded Dual-In-Line Package (N)
Order Number LM2907N or LM2917N
NS Package Number N14A

Notes

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

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Fax 81-3-5639-7507

LM2907 Tachometer/Speed Switch Building Block Applications

National Semiconductor
Application Note 162
June 1976

INTRODUCTION

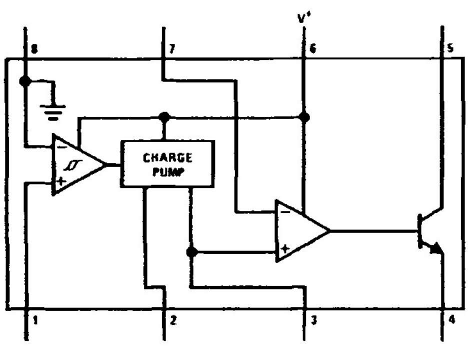
Frequency to voltage converters are available in a number of forms from a number of sources, but invariably require significant additional components before they can be put to use in a given situation. The LM2907, LM2917 series of devices was developed to overcome these objections. Both input and output interface circuitry is included on chip so that a minimum number of additional components is required to complete the function. In keeping with the systems building block concept, these devices provide an output voltage which is proportional to input frequency and provide zero output at zero frequency. In addition, the input may be referred to ground. The devices are designed to operate from a single supply voltage, which makes them particularly suitable for battery operation.

PART 1—GENERAL OPERATION PRINCIPLES

Circuit Description

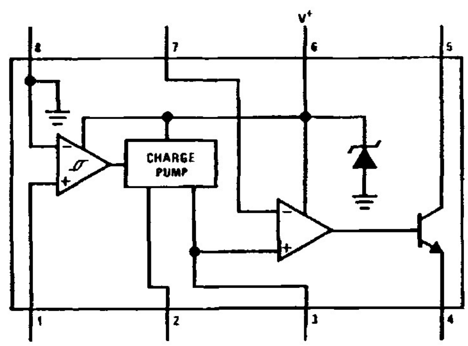
Referring to *Figure 1*, the family of devices all include three basic components: an input amplifier with built-in hysteresis; a charge pump frequency to voltage converter; and a versatile op amp/comparator with an uncommitted output transistor. LM2917 incorporates an active zener regulator on-chip. LM2907 deletes this option. Both versions are obtainable in 14-pin and in 8-pin dual-in-line molded packages, and to special order in other packages.

LM2907N-8



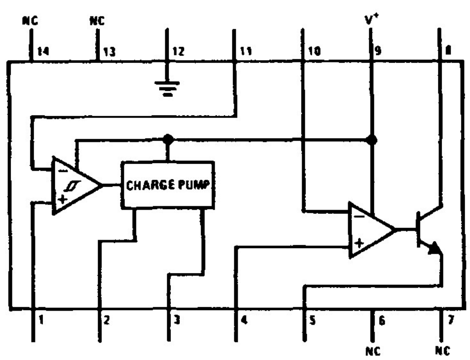
TL/H/7451-1

LM2917N-8



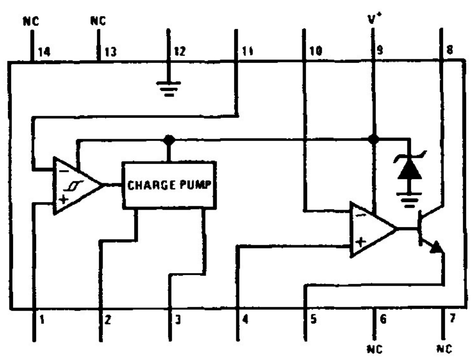
TL/H/7451-2

LM2907N



TL/H/7451-3

LM2917N



TL/H/7451-4

FIGURE 1. Block Diagrams

RRD-B30M115/Printed in U. S. A.

Input Hysteresis Amplifier

The equivalent schematic diagram is shown in *Figure 2*. Q1 through Q11 comprise the input hysteresis amplifier. Q1 through Q4 comprise an input differential amplifier which, by virtue of PNP level shifting, enables the circuit to operate with signals referenced to ground. Q7, Q8, D4, and D5 comprise an active load with positive feedback. This load behaves as a bi-stable flip-flop which may be set or reset depending upon the currents supplied from Q2 and Q3. Consider the situation where Q2 and Q3 are conducting equally, i.e. the input differential voltage is zero. Assuming Q7 to be conducting, it will be noted that the current from Q3 will be drawn by Q7 and Q8 will be in the "OFF" state. This allows the current from Q2 to drive Q7 in parallel with D4 and a small resistor. D4 and Q7 are identical geometry devices, so that the resistor causes Q7 to be biased at a higher level than D4. Thus Q7 will be able to conduct more current than Q3 provides. In order to reverse the state of Q7 and Q8, it will be necessary to reduce the current from Q2 below that provided by Q3 by an amount which is established by R1. It can be shown that this requires a differential input to Q1 and Q4, of approximately 15mV. Since the circuit is symmetrical, the threshold voltage to reverse the state is 15 mV in the other direction. Thus the input amplifier has built-in hysteresis at ±15 mV. This provides clean switching where noise may be present on the input signal, and allows total rejection of noise below this amplitude where there is no input signal.

Charge Pump

The charge pump is composed of Q12 through Q32. R4, R5, and R6 provide reference voltages equal to 1/4 and 3/4 of supply voltage to Q12 and Q13. When Q10 turns "ON" or "OFF," the base voltage at Q16 changes by an amount equal to the voltage across R5, that is 1/2 V_{CC}. A capacitor connected between Pin 2 and ground is either charged by Q21 or discharged by Q22 until its voltage matches that on the base of Q16. When the voltage on Q16 base goes low, Q16 turns "ON," which results in Q18 and Q26 turning on, which causes the current, sourced by Q19 and Q20, to be shunted to ground. Thus Q21 is unable to charge pin 2. Meanwhile, Q27 and Q30 are turned off permitting the 200 μA sourced by Q28 and Q29 to enter the emitters of Q31 and Q32 respectively. The current from Q31 is mirrored by Q22 through Q24 resulting in a 200 μA discharge current through pin 2. The external capacitor on pin 2 is thus discharged at a constant rate until it reaches the new base voltage on Q16. The time taken for this discharge to occur is given by:

$$t = \frac{CV}{I} \qquad (1)$$

where C = capacitor on pin 2

V = change in voltage on Q16 base

I = current in Q22

During this time, Q32 sources an identical current into pin 3. A capacitor connected to pin 3 will thus be charged by the same current for the same amount of time as pin 2. When the base voltage on Q16 goes high, Q18 and Q26 are turned off while Q27 and Q30 are turned "ON." In these conditions, Q21 and Q25 provide the currents to charge the capacitors on pins 2 and 3 respectively. Thus the charge required to return the capacitor on pin 2 to the high level voltage is duplicated and used to charge the capacitor connected to pin 3. Thus in one cycle of input the capacitor on pin 3 gets charged twice with a charge of CV.

Thus the total charge pumped into the capacitor on pin 3 per cycle is:

$$Q = 2CV \qquad (2)$$

Now, since $V = V_{CC}/2$

then $$Q = CV_{CC} \qquad (3)$$

A resistor connected between pin 3 and ground causes a discharge of the capacitor on pin 3, where the total charge drained per cycle of input signal is equal to:

$$Q1 = \frac{V3 \bullet T}{R}$$

where V3 = the average voltage on pin 3

T = period of input signal

R = resistor connected to pin 3

In equilibrium Q = Q1

$$\text{i.e., } CV_{CC} = \frac{V3 \bullet T}{R} \qquad (4)$$

and $$V3 = V_{CC} \bullet \frac{RC}{T} \qquad (5)$$

or $$V3 = V_{CC} \bullet R \bullet C \bullet f \qquad (6)$$

where f = input frequency

Op Amp/Comparator

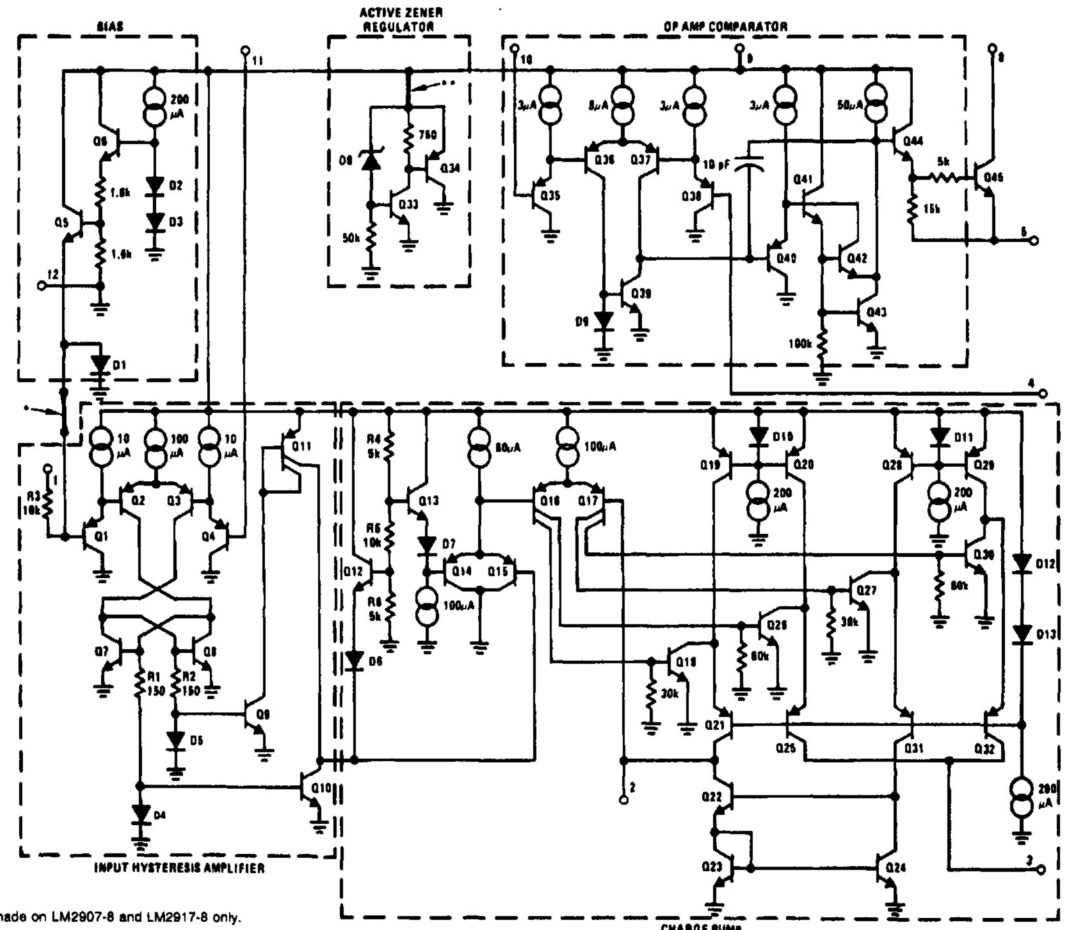
Again referring to *Figure 2*, the op amp/comparator includes Q35 through Q45. A PNP input stage again provides input common-mode voltages down to zero, and if pin 8 is connected to V_{CC} and the output taken from pin 5, the circuit behaves as a conventional, unity-gain-compensated operational amplifier. However, by allowing alternate connections of Q45 the circuit may be used as a comparator in which loads to either V_{CC} or ground may be switched. Q45 is capable of sinking 50 mA. Input bias current is typically 50 nA, and voltage gain is typically 200 V/mV. Unity gain slew rate is 0.2 V/μs. When operated as a comparator Q45 emitter will switch at the slew rate, or the collector of Q45 will switch at that rate multiplied by the voltage gain of Q45, which is user selectable.

Active Zener Regulator

The optional active zener regulator is also shown in *Figure 2*. D8 provides the voltage reference in conjunction with Q33. As the supply voltage rises, D8 conducts and the base voltage on Q33 starts to rise. When Q33 has sufficient base voltage to be turned "ON," it in turn causes Q34 to conduct current from the power source. This reduces the current available for D8 and the negative feedback loop is thereby completed. The reference voltage is therefore the zener voltage on D8 plus the emitter base voltage of Q33. This results in a low temperature coefficient voltage.

Input Levels and Protection

In 8-pin versions of the LM2907, LM2917, the non-inverting input of the op amp/comparator is connected to the output of the charge pump. Also, one input to the input hysteresis amplifier is connected to ground. The other input (pin 1) is then protected from transients by, first a 10kΩ series resis-



*Note: This connection made on LM2907-8 and LM2917-8 only.

**Note: This connection made on LM2917 and LM2917-8 only.

Note: Pin numbers refer to 14-pin package.

TL/H/7451-5

FIGURE 2. Equivalent Schematic Diagram

tor, R3 *(Figure 2)* which is located in a floating isolation pocket, and secondly by clamp diode D1. Since the voltage swing on the base of Q1 is thus restricted, the only restriction on the allowable voltage on pin 1 is the breakdown voltage of the 10 kΩ resistor. This allows input swings to ±28V. In 14-pin versions the link to D1 is opened in order to allow the base of Q1 to be biased at some higher voltage.

Q5 clamps the negative swing on the base of Q1 to about 300 mV. This prevents substrate injection in the region of Q1 which might otherwise cause false switching or erroneous discharge of one of the timing capacitors.

The differential input options (LM2907-14, LM2917-14), give the user the option of setting his own input switching level and still having the hysteresis around that level for excellent noise rejection in any application.

HOW TO USE IT

Basic f to V Converter

The operation of the LM2907, LM2917 series is best understood by observing the basic converter shown in *Figure 3*. In this configuration, a frequency signal is applied to the input of the charge pump at pin 1. The voltage appearing at pin 2 will swing between two values which are approximately 1/4 $(V_{CC}) - V_{BE}$ and 3/4 $(V_{CC}) - V_{BE}$. The voltage at pin 3 will have a value equal to $V_{CC} \bullet f_{IN} \bullet C1 \bullet R1 \bullet K$, where K is the gain constant (normally 1.0).

The emitter output (pin 4) is connected to the inverting input of the op amp so that pin 4 will follow pin 3 and provide a low impedance output voltage proportional to input frequency. The linearity of this voltage is typically better than 0.3% of full scale.

Choosing R1, C1 and C2

There are some limitations on the choice of R1, C1 and C2 *(Figure 3)* which should be considered for optimum performance. C1 also provides internal compensation for the charge pump and should be kept larger than 100 pF. Smaller values can cause an error current on R1, especially at low temperatures. Three considerations must be met when choosing R1.

First, the output current at pin 3 is internally fixed and therefore V3 max, divided by R1, must be less than or equal to this value.

$$\therefore R1 \geq \frac{V3\ max}{I_{3MIN}}$$

where V3 max is the full scale output voltage required

I_{3MIN} is determined from the data sheet (150 μA)

Second, if R1 is too large, it can become a significant fraction of the output impedance at pin 3 which degrades linearity. Finally, ripple voltage must be considered, and the size of C2 is affected by R1. An expression that describes the ripple content on pin 3 for a single R1, C2 combination is:

$$V_{RIPPLE} = \frac{V_{CC}}{2} \bullet \frac{C1}{C2}\left(1 - \frac{V_{CC} \bullet f_{IN} \bullet C1}{I_2}\right) \text{p-p}$$

It appears R1 can be chosen independent of ripple, however response time, or the time it takes V_{OUT} to stabilize at a new frequency increases as the size of C2 increases, so a compromise between ripple, response time, and linearity must be cosen carefully. R1 should be selected according to the following relationship:

C is selected according to:

$$C1 = \frac{V3\ \text{Full Scale}}{R1 \bullet V_{CC} \bullet f_{FULL\ SCALE}}$$

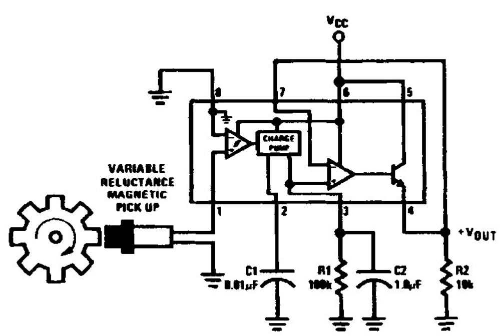
Next decide on the maximum ripple which can be accepted and plug into the following equation to determine C2:

$$C2 = \frac{V_{CC}}{2} \bullet \frac{C1}{V_{RIPPLE}}\left(1 - \frac{V_3}{R_1 I_2}\right)$$

The kind of capacitor used for timing capacitor C1 will determine the accuracy of the unit over the temperature range. *Figure 15* illustrates the tachometer output as a function of temperature for the two devices. Note that the LM2907 operating from a fixed external supply has a negative temperature coefficient which enables the device to be used with capacitors which have a positive temperature coefficient and thus obtain overall stability. In the case of the LM2917 the internal zener supply voltage has a positive coefficient which causes the overall tachometer output to have a very low temperature coefficient and requires that the capacitor temperature coefficient be balanced by the temperature coefficient of R1.

Using Zener Regulated Options (LM2917)

For those applications where an output voltage or current must be obtained independently of the supply voltage variations, the LM2917 is offered. The reference typically has an 11Ω source resistance. In choosing a dropping resistor from the unregulated supply to the device note that the tachometer and op amp circuitry alone require about 3 mA at the voltage level provided by the zener. At low supply voltages,



TL/H/7451-6

FIGURE 3. Basic f to V Converter

there must be some current flowing in the resistor above the 3 mA circuit current to operate the regulator. As an example, if the raw supply varies from 9V to 16V, a resistance of 470Ω will minimize these zener voltage variations to 160 mV. If the resistor goes under 400Ω or over 600Ω the zener variation quickly rises above 200 mV for the same input variation. Take care also that the power dissipation of the IC is not exceeded at higher supply voltages. *Figure 4* shows suitable dropping resistor values.

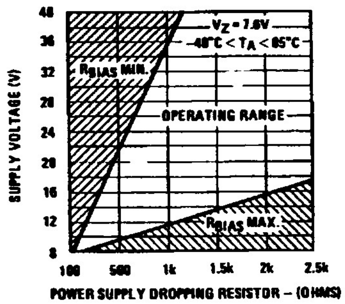


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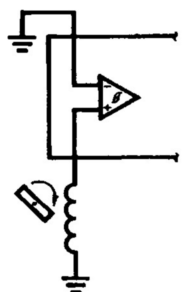
FIGURE 4. Zener Regular Bias Resistor Range

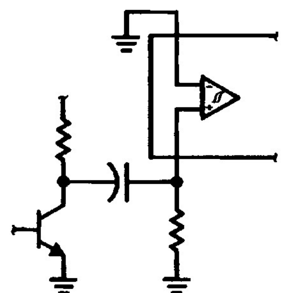
Input Interface Circuits

The ground referenced input capability of the LM2907-8 allows direct coupling to transformer inputs, or variable reluctance pickups. *Figure 5(a)* illustrates this connection. In many cases, the frequency signal must be obtained from another circuit whose output may not go below ground. This may be remedied by using ac coupling to the input of the LM2907 as illustrated in *Figure 5(b)*. This approach is very suitable for use with phototransistors for optical pickups. Noisy signal sources may be coupled as shown in *Figure 5(c)*. The signal is bandpass filtered. This can be used, for example, for tachometers operating from breakerpoints on a conventional Kettering ignition system. Remember that the minimum input signal required by the LM2907 is only 30 mVp-p, but this signal must be able to swing at least 15 mV on either side of the inverting input. The maximum signal which can be applied to the LM2907 input, is ±28V. The input bias current is a typically 100 nA. A path to ground must be provided for this current through the source or by other means as illustrated. With 14-pin package versions of LM2907, LM2917, it is possible to bias the inverting input to the tachometer as illustrated in *Figure 5(d)*. This enables the circuit to operate with input signals that do not go to ground, but are referenced at higher voltages. Alternatively, this method increases the noise immunity where large signal



TL/H/7451-8

(a) Ground Referenced Inputs



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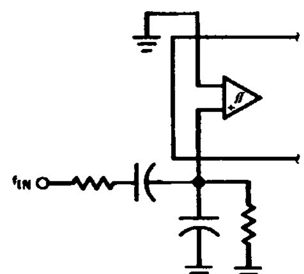
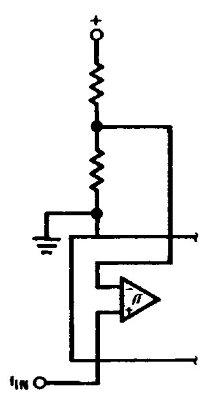
(b) AC Coupled Input



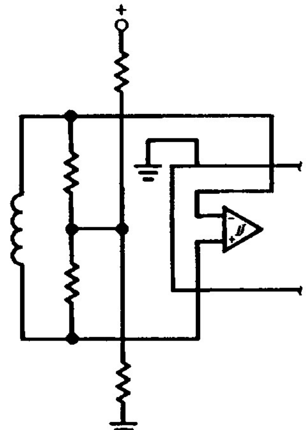
TL/H/7451-10

(c) Bandpass Filtered Input Reduces Noise



TL/H/7451-11

(d) Above Ground Sensing



TL/H/7451-12

(e) High Common-Mode Rejection Input Circuit

FIGURE 5. Tachometer Input Configurations

levels are available but large noise signals on ground are also present. To take full advantage of the common-mode rejection of the input differential stage, a balanced bias configuration must be provided. One such circuit is illustrated in *Figure 5(e)*. With this arrangement, the effective common-mode rejection may be virtually infinite, owing to the input hysteresis.

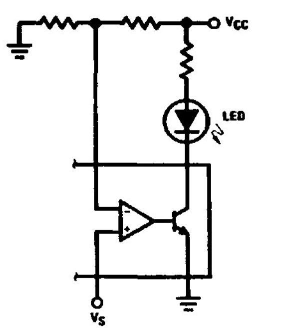
Output Configurations

LM2907, LM2917 series devices incorporate an unusually flexible op amp/comparator device on-chip for interfacing with a wide variety of loads. This flexibility results from the availability of both the collector and emitter of the output transistor which is capable of driving up to 50 mA of load current. When the non-inverting input is higher than the inverting input, this output transistor is turned "ON". It may be used to drive loads to either the positive or the negative supply with the emitter or collector respectively connected to the other supply. For example, *Figure 6(a)*, a simple speed switch can be constructed in which the speed signal derived from the frequency to voltage converter is compared to a reference derived simply by a resistive divider from the power supply. When the speed signal exceeds the reference, the output transistor turns on the light emitting diode in the load. A small current limiting resistor should be placed in series with the output to protect the LED and the output transistor.

This circuit has no hysteresis in it, i.e., the turn "ON" and turn "OFF" speed voltages are essentially equal. In cases where speed may be fluctuating at a high rate and a flashing LED would be objectionable, it is possible to incorporate hysteresis so that the switch-on speed is above the switch-off speed by a controlled amount. Such a configuration is illustrated in *Figure 6(b)*. *Figure 6(c)* shows how a grounded load can also be switched by the circuit. In this case, the current limiting resistor is placed in the collector of the power transistor. The base current of the output transistor (Q45) is limited by a 5 kΩ base resistor (see *Figure 2*). This raises the output resistance so that the output swing will be reduced at full load.

The op amp/comparator is internally compensated for unity gain feedback configurations as in *Figure 6(d)*. By directly connecting the emitter output to the non-inverting input, the op amp may be operated as a voltage follower. Note that a load resistor is required externally. The op amp can also be operated, of course, as an amplifier, integrator, active filter, or in any other normal operational amplifier configuration.

One unique configuration which is not available with standard operational amplifiers, is shown in *Figure 6(e)*. Here the collector of the output transistor is used to drive a load



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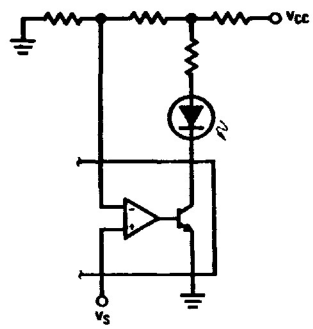
(a) Switching an LED



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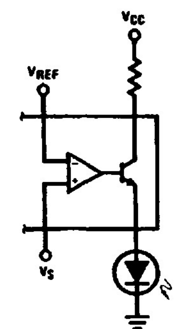
(b) Adding Hysteresis to LED Switch



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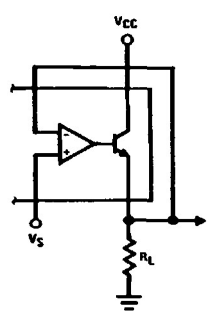
(c) Switching a Grounded Load



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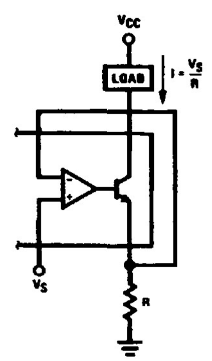
(d) Voltage Follower



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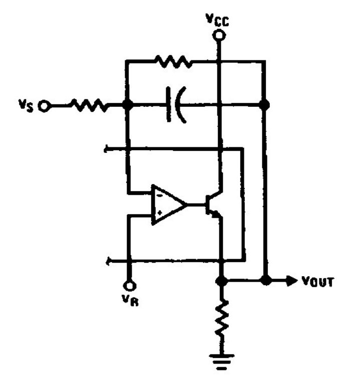
(e) Voltage to Current Converter



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(f) Integrator

FIGURE 6. Output Configurations

with a current which is proportional to the input voltage. In other words, the circuit is operating as a voltage to current converter. This is ideal for driving remote signal sensors and moving coil galvanometers. *Figure 6(f)* shows how an active integrator can be used to provide an output which falls with increasing speed.

These are the basic configurations obtainable with the op amp/comparator. Further combinations can be seen in the applications shown in Part II of this application note.

Transient Protection

Many application areas use unregulated power supplies which tend to expose the electronics to potentially damaging transients on the power supply line. This is particularly true in the case of automotive applications where two such transients are common.[1] First is the load dump transient. This occurs when a dead battery is being charged at a high current and the battery cable comes loose, so that the current in the alternator inductance produces a positive transient on the line in the order of 60V to 120V. The second transient is called field decay. This occurs when the ignition is turned "OFF" and the energy stored in the field winding of the alternator causes a negative 75V transient on the ignition line.

Figure 7 illustrates methods for protecting against these and other transients. *Figure 7(a)* shows a typical situation in which the power supply to the LM2907 can be provided through a dropping resistor and regulated by an external zener diode Z1, but the output drive is required to operate from the full available supply voltage. In this case, a separate protection zener Z2 must be provided if the voltage on the power line is expected to exceed the maximum rated voltage of the LM2907.

In *Figure 7(b)* and *Figure 7(c)*, the output transistor is required only to drive a simple resistive load and no secondary protection circuits are required. (Note that the dropping resistor to the zener also has to supply current to the output circuit). With the foregoing circuits, reverse supply protection is supplied by the forward biased zener diode. This device should be a low forward resistance unit in order to limit the maximum reverse voltage applied to the integrated circuit. Excessive reverse voltage on the IC can cause high currents to be conducted by the substrate diodes with consequent danger of permanent damage. Up to 1V negative can generally be tolerated. Versions with internal zeners may be self-protecting depending on the size of dropping resistor used. In applications where large negative voltage

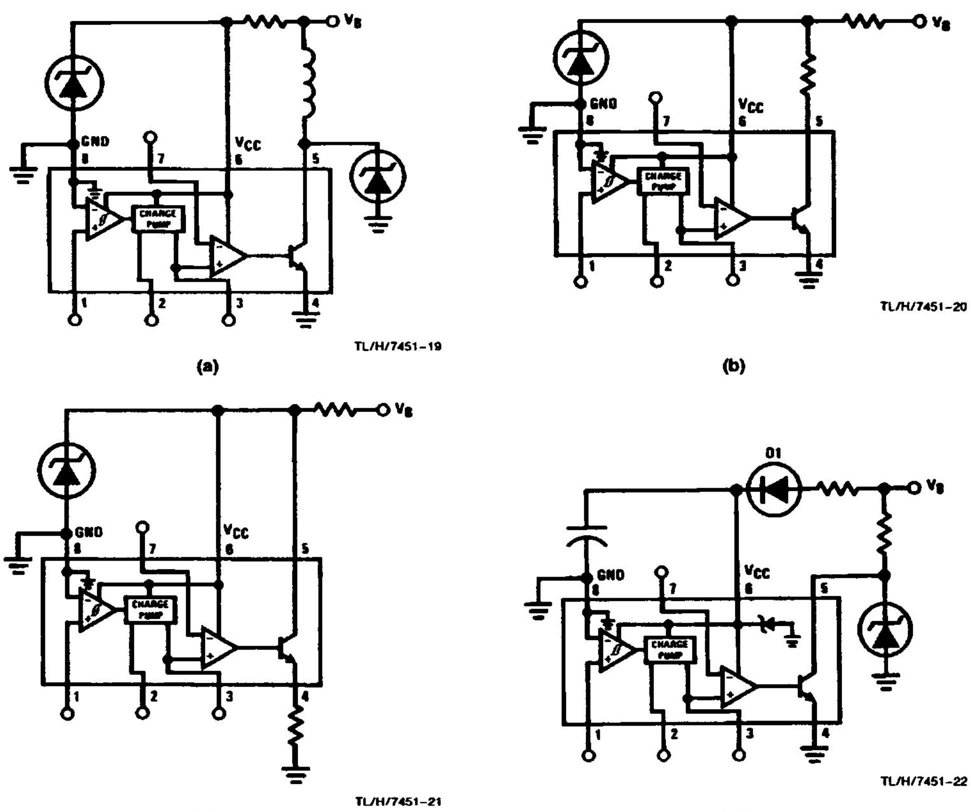

FIGURE 7. Transient Protection Schemes

transients may be anticipated, a blocking diode may be connected in the power supply line to the IC as illustrated in *Figure 7(d)*. During these negative transients, the diode D1 will be reverse biased and prevent reverse currents flowing in the IC. If these transients are short and the capacitor C1 is large enough, then the power to the IC can be sustained. This is useful to prevent change of state or change of charge in in systems connected to it.

Temperature Ranges and Packaging Considerations

The LM2907, LM2917 series devices are specified for operation over the temperature range $-40°C$ to $+85°C$.

The devices are normally packaged in molded epoxy, dual-in-line packages. Other temperature ranges and other packages are availabe to special order. For reliability requirements beyond those of normal commercial application where the cost of military qualification is not bearable, other programs are available such as B+.

PART II—APPLICATIONS

INTRODUCTION

The LM 2907, LM2917 series devices were designed not only to perform the basic frequency to voltage function required in many systems, but also to provide the input and output interface so often needed, so that low cost implementations of complete functions are available.

The concept of building blocks requires that a function be performed in the same way as it can be mathematically defined. In other words, a frequency to voltage converter will provide an output voltage proportional to frequency which is independent of the input voltage or other input parameters, except the frequency. In the same way, the output voltage will be zero when the input frequency is zero. These features are built into the LM2907.

Applications for the device range from simple speed switch for anti-pollution control device functions in automobiles, to motor speed controls in industrial applications. The applications circuits which follow are designed to illustrate some of the capabilities of the LM2907. In most cases, alternative input or output configurations can be mixed and matched at will and other variations can be determined from the description in Part I of this application note. For complete specifications, refer to the data sheet.

Speed Switches

Perhaps the most natural application of the LM2907 is in interfacing with magnetic pickups, such as the one illustrated in *Figure 8* to perform speed switching functions. As an example, New York taxies are required to change the intensity of the warning horn above and below 45 mph. Other examples include an over-speed warning, where a driver may set the desired maximum speed and have an audible

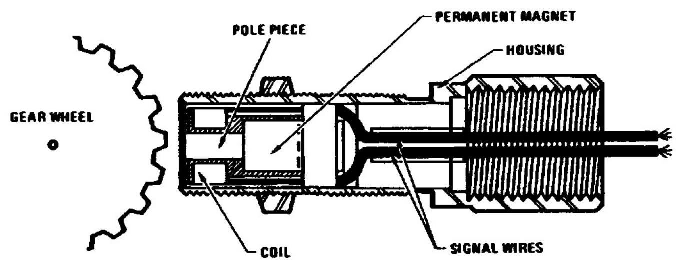

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FIGURE 8. Typical Magnetic Pickup

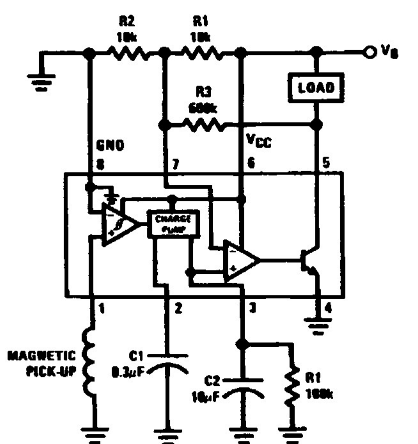

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FIGURE 9. Simple Speed Switch Load is Energized when $f_{IN} > \frac{1}{2C1R1}$

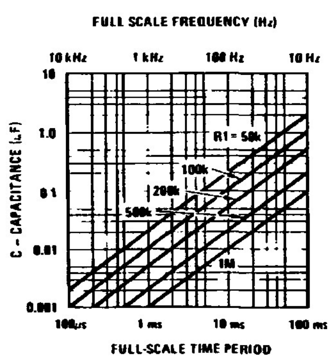

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FIGURE 10. RC Selection Chart

or visual warning of speeds in excess of that level. Many anti-pollution devices included on several recent automobile models have included a speed switch to disable the vacuum advance function until a certain speed is attained[2]. A circuit which will perform these kind of functions is shown in *Figure 9*. A typical magnetic pickup for automotive applications will provide a thousand pulses per mile so that at 60 mph the incoming frequency will be 16.6 Hz. If the reference level on the comparator is set by two equal resistors R1 and R2 then the desired value of C1 and R1 can be determined from the simple relationship:

$$\frac{V_{CC}}{2} = V_{CC} \bullet C1 \bullet R1 \bullet f.$$

or $\quad C1R1f = 0.5$

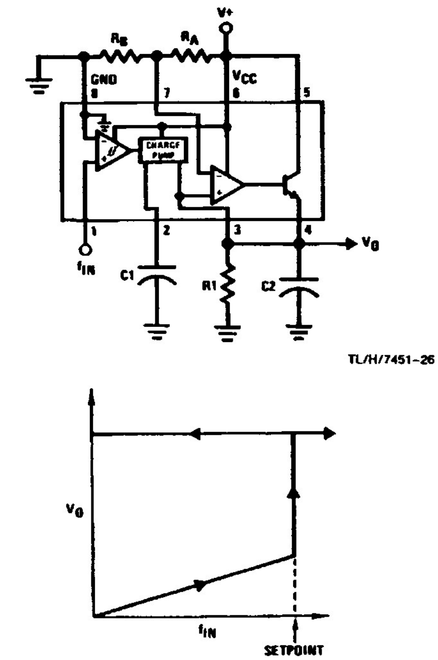
and hence $\quad C1R1 = 0.03$

From the RC selection chart in *Figure 10* we can choose suitable values for R1 and C1. Examples are 100 kΩ and 0.3 μF. The circuit will then switch at approximately 60 mph with the stated input frequency relationship to speed. To determine the ripple voltage refer back to the equation for ripple voltage (under "Choosing R1, C1 and C2"). From this we can determine that there will be about 10 mV of ripple at the switching level. To prevent this from causing chattering of the load a certain amount of hysteresis is added by including R3. This will provide typically 1% of supply as a hysteresis or 1.2 mph in the example. Note that since the reference to the comparator is a function of supply voltage as is the output from the charge pump there is no need to regulate the power supply. The frequency at which switching occurs is independent of supply voltage.

In some industrial applications it is useful to have an indication of past speed excesses, for example in notifying the need for checking of bearings. The LM2907 can be made to latch until the power supply is turned "OFF" in the case where the frequency exceeds a certain limit, by simply connecting the output transistor emitter back to the non-inverting input of the comparator as shown in *Figure 11*. It can also serve to shut off a tape recorder or editing machine at the end of a rewind cycle. When the speed suddenly increases, the device will sense the condition and shut down the motor.

Analog Displays

The LM2907, LM2917 series devices are particularly useful for analog display of frequency inputs. In situations where the display device is a moving coil instrument the advantages of the uncommitted output transistor can be realized by providing a current drive to the meter. This avoids temperature tracking problems with the varying meter resistance and enables high resistance instruments to be driven accurately with relatively large voltages as illustrated in *Figure 12*. The LM2917 version is employed here to provide a regulated current to the instrument. The onboard 7.6V zener is compatible with car and boat batteries and enables the moving coil instrument to employ the full battery voltage for its deflection. This enables high torque meters to be used. This is particularly useful in high vibration environments such as boats and motorcycles. In the case of boats, the most common speed pickup for the knot meter employs a rotating propeller driving a magnetic pickup device. Meteorologists employ a large number of anemometers for measuring wind velocities and these are frequently coupled by a magnetic pickup. In examples like these, where there is frequently a large distance between the display device and the sensor, the configuration of *Figure 13* can be usefully employed to cut down on the number of wires needed. Here the output current is conducted along the supply line so that a local current sensing device in the supply line can be used to get a direct reading of the frequency at the remote location where the electronics may also be situated. The small zero speed offset due to the device quiescent current may be compensated by offsetting the zero on the display device. This also permits one display device to be shared between several inputs.



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$V_O = F_{IN}V + R1\,C1$

$SETPOINT = V + \frac{RB}{RD + RA}$

Latchup occurs when $F_{IN} = \frac{RB}{RA + RB}\frac{1}{R1\,C1}$

Independent of V + !

FIGURE 11. Overspeed Latch

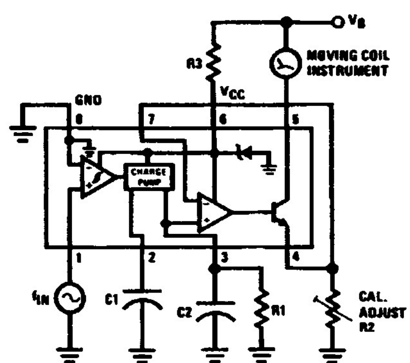

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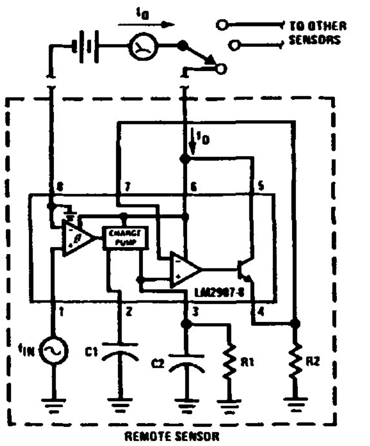
FIGURE 12. Analog Display of Frequency



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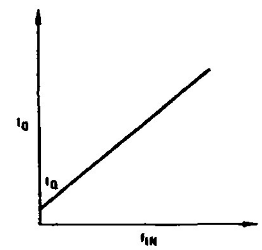

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FIGURE 13. Two Wire Remote Speed Sensor

Automotive Tachometer

Not all inputs are derived from variable reluctance magnetic pickups; for example, in spark ignition engines the tachometer is generally driven from the spark coil. An interface circuit for this situation is shown in *Figure 14.* This tachometer can be set up for any number of cylinders by linking the appropriate timing resistor as illustrated. A 500Ω trim resistor can be used to set up final calibration. A protection circuit composed of a 10Ω resistor and a zener diode is also shown as a safety precaution against the transients which are to be found in automobiles.

Motor Speed Controls

DC motors with or without brushes can be purchased with ac tachometer outputs already provided by the manufacturer[3]. With these motors in combination with the

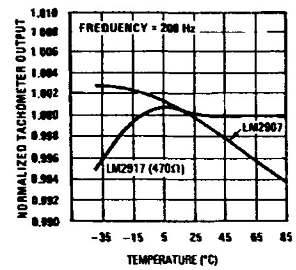

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FIGURE 15. Normalized Tachometer Output vs. Temperature

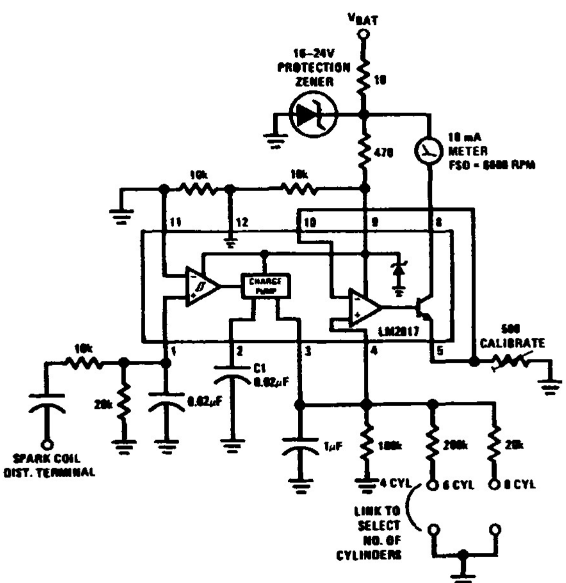

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FIGURE 14. Gasoline Engine Tachometer

LM2907, a very low cost speed control can be constructed. In *Figure 16* the most simple version is illustrated where the tachometer drives the non-inverting input of the comparator up towards the preset reference level. When that level is reached, the output is turned off and the power is removed from the motor. As the motor slows down, the voltage from the charge pump output falls and power is restored. Thus speed is maintained by operating the motor in a switching mode. Hysteresis can be provided to control the rate of switching. An alternative approach which gives proportional control is shown in *Figure 17.* Here the charge pump integrator is shown in a feedback connection around the operational amplifier. The output voltage for zero speed is equal to the reference voltage set up on the potentiometer on the non-inverting input. As speed increases, the charge pump puts charge into capacitor C2 and causes the output V_{OUT} to fall in proportion to speed. The output current of the op amp transistor is used to provide an analog drive to the motor. Thus as the motor speed approaches the reference level, the current is proportionately reduced to the motor so that the motor gradually comes up to speed and is maintained without operating the motor in a switching mode. This is particularly useful in situations where the electrical noise generated by the switching mode operation is objectionable. This circuit has one primary disadvantage in that it has poor load regulation. A third configuration is shown in *Figure 18.* This employs an LM2907-8 acting as a shunt mode regulator. It also features an LED to indicate when the device is in regulation.

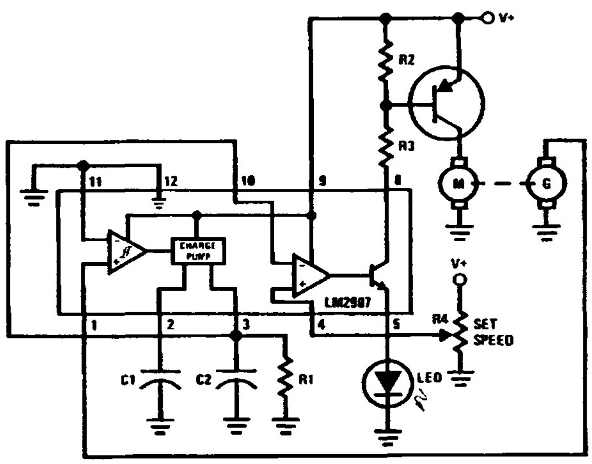

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FIGURE 16. Motor Speed Control

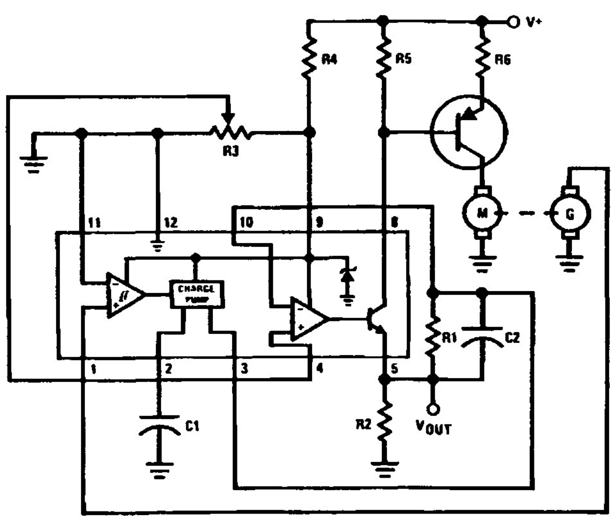

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FIGURE 17. Motor Speed Control with Proportional Drive

Position Sensing

In addition to their use to complete tachometer feedback loops, used in position transducer circuits, the LM2907, LM2917 devices can also be used as position transducers. For example, the timing resistor can be removed from pin 3 so that the output current produces a staircase instead of a fixed dc level. If the magnetic pickup senses passing notches or items, a staircase signal is generated which can then be compared with a reference to initiate a switching action when a specified count is reached. For example, *Figure 19* shows a circuit which will count up a hundred input pulses and then switch on the output stage. Examples of this application can be found in automated packaging operations or in line printers.

The output of the tachometer is proportional to the product of supply voltage, input frequency, a capacitor and a resistor. Any one of these may be used as the input variable or they may be used in combination to produce multiplication. An example of a capacitive transducer is illustrated in *Figure 20*, where a fixed input frequency is employed either from the 60 Hz line as a convenient source or from a stable oscillator. The capacitor is a variable element mechanically coupled to the system whose position is to be sensed. The output is proportional to the capacitance value, which can be arranged to have any desired relationship to the mechanical input by suitable shaping of the capacitor electrodes.

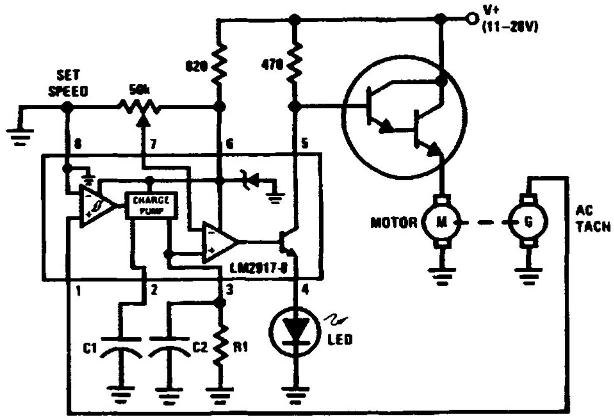

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FIGURE 18. Motor Speed Control

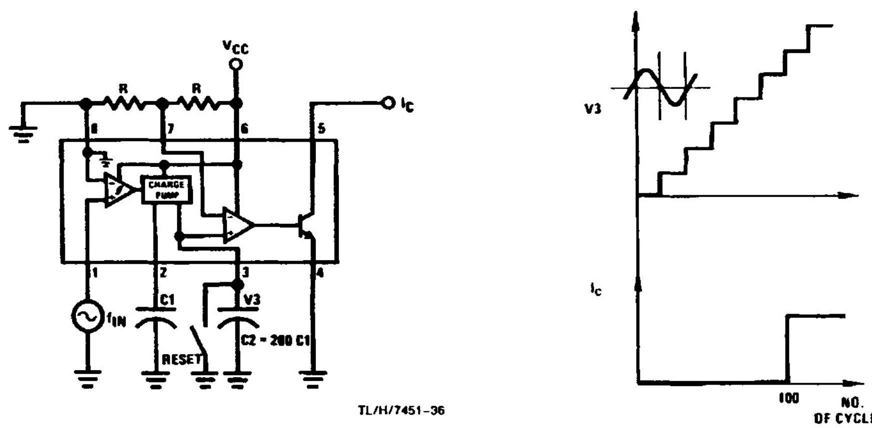

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FIGURE 19. Staircase Counter

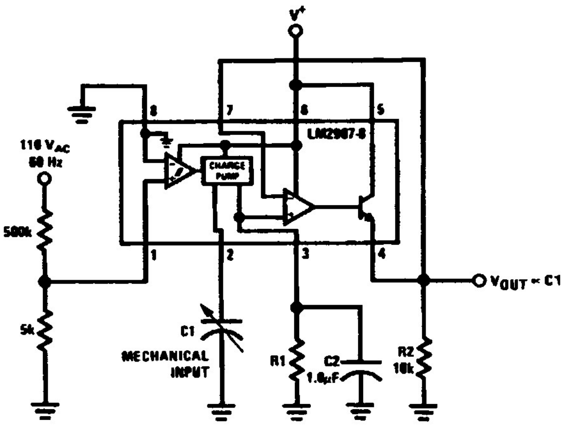

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FIGURE 20. Capacitive Transducer

Analog Systems Building Block

The LM2907, LM2917 series characterize systems building block applications by the feature that the output from the device is proportional only to externally programmed inputs. Any or all of these inputs may be controlled inputs to provide the desired output. For example, in *Figure 20* the capacitance transducer can be operated as a multiplier. In flow measurement indicators, the input frequency can be a variable depending on the flow rate, such as a signal generated from a paddle wheel, propeller or vortex sensor[4]. The capacitor can be an indication of orifice size or aperture size, such as in a throttle body. The product of these two will indicate volume flow. A thermistor could be added to R1 to convert the volume flow to mass flow. So a combination of these inputs, including control voltage on the supply, can be used to provide complex multiplicative analog functions with independent control of the variables.

Phase-locked loops (PLL) are popular today now that low cost monolithic implementations are available off the shelf. One of their limitations is the narrow capture range and hold-in range. The LM2907 can be employed as a PLL helper. The configuration is shown in *Figure 21*. The LM2907 here serves the function of a frequency-to-voltage converter which puts the VCO initially at approximately the right frequency to match the input frequency. The phase detector is then used to close the gap between VCO and input frequency by exerting a control on the summing point. In this way, given proper tracking between the frequency-to-voltage converter and the VCO, (which is a voltage-to-frequency converter), a wide-range phase loop can be developed.

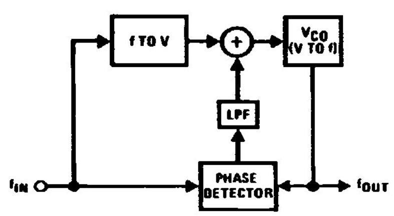

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FIGURE 21. Phase-Locked Loop Helper Added f to V Greatly Increases Capture and Hold Range

The linearity of voltage controlled oscillators can be improved by employing the LM2907 as a feedback control element converting the frequency back to voltage and comparing with the input voltage. This can often be a lower cost solution to linearizing the VCO than by working directly on the VCO itself in the open loop mode. The arrangement is illustrated in *Figure 22*.

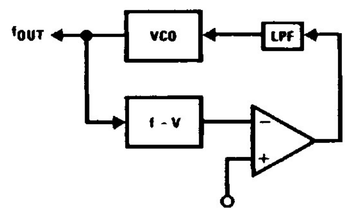

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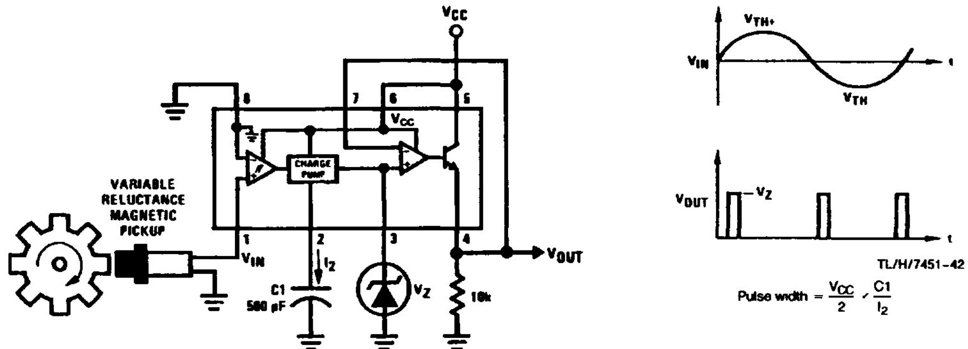
FIGURE 22. Feedback Controlled VCO

Digital Interface

A growing proportion of the complex control systems today are being controlled by microprocessors and other digital devices. Frequently they require inputs to indicate position or time from some mechanical input. The LM2907 can be used to provide zero crossing datum to a digital system using the circuits illustrated in *Figure 23*. At each zero crossing of the input signal the charge pump changes the state of capacitor C1 and provides a one-shot pulse into the zener diode at pin 3. The width of this pulse is controlled by the internal current of pin 2 and the size of capacitor C1 as well as by the supply voltage. Since a pulse is generated by each zero crossing of the input signal we call this a "two-shot" instead of a "one-shot" device and this can be used for doubling the frequency that is presented to the microprocessor control system. If frequency doubling is not required and a square wave output is preferred, the circuit of *Figure 24* can be employed. In this case, the output swing is the same as the swing on pin 2 which is a swing of half supply voltage starting at 1 V_{BE} below one quarter of supply and going to 1 V_{BE} below three-quarters of supply. This can be increased up to the full output swing capability by reducing or removing the negative feedback around the op amp.

The staircase generator shown in *Figure 19* can be used as an A-D converter. A suitable configuration is shown in *Figure 25.* To start a convert cycle the processor generates a reset pulse to discharge the integrating capacitor C2. Each complete clock cycle generates a charge and discharge cycle on C1. This results in two steps per cycle being added to C2. As the voltage on C2 increases, clock pulses are returned to the processor. When the voltage on C2 steps above the analog input voltage the data line is clamped and C2 ceases to charge. The processor, by counting the number of clock pulses received after the reset pulse, is thus loaded with a digital measure of the input voltage. By making C2/C1 = 1024 an 8-bit A-D is obtained.



Input can be ±20 mV to ±28V

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Output frequency equal twice input frequency. Pulse width $= \frac{V_{CC}}{2} \times \frac{C1}{I_2}$ Pulse height $= V_{ZENER}$

FIGURE 23. "Two-Shot" Zero Crossing Detector

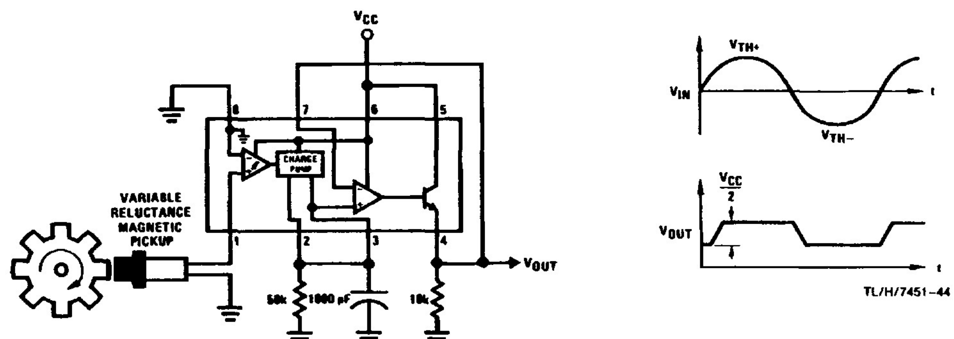

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FIGURE 24. Zero Crossing Detector and Line Drivers

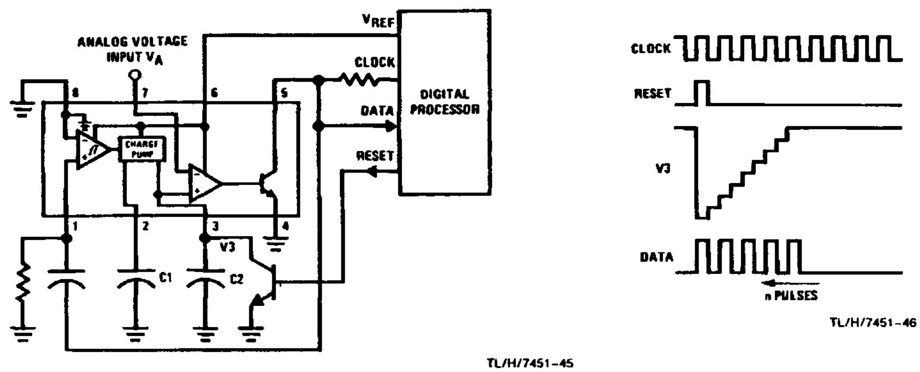

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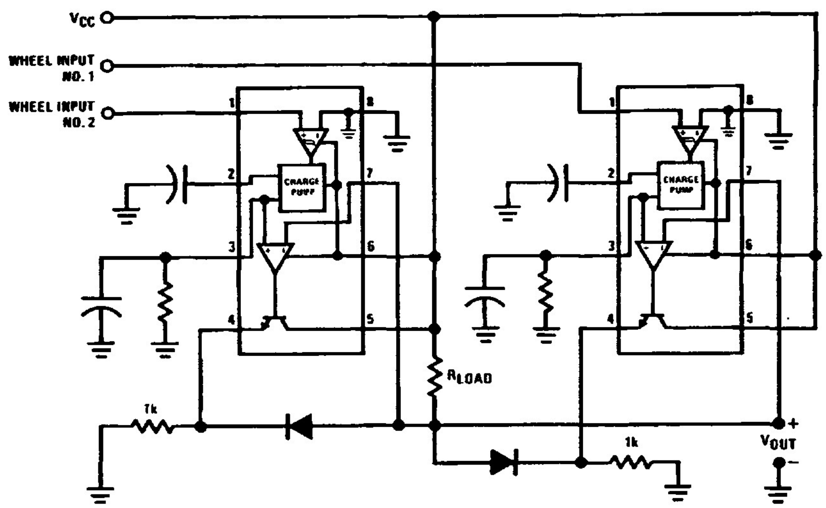
FIGURE 25. A-D Converter

Anti-Skid Circuit Functions

Motor Vehicle Standards 121 place certain stopping requirements on heavy vehicles which require the use of electronic anti-skid control devices.[5] These devices generally use variable reluctance magnetic pickup sensors on the wheels to provide inputs to a control module. One of the questions which the systems designer must answer is whether to use the average from each of the two wheels on a given axle or to use the lower of the two speeds or to use the higher of the two speeds. Each of the three functions can be generated by a single pair of LM2907-8 as illustrated in *Figures 26–28*. In *Figure 26* the input frequency from each wheel sensor is converted to a voltage in the normal manner. The op amp/comparator is connected with negative feedback with a diode in the loop so that the amplifier can only pull down on the load and not pull up. In this way, the outputs from the two devices can be joined together and the output will be the lower of the two input speeds. In *Figure 27* the output emitter of the onboard op amp provides the pullup required to provide a select-high situation where the output is equal to the higher of two speeds. The select average circuit in *Figure 28* saves components by allowing the two charge pumps to operate into a single RC network. One of the amplifiers is needed then to buffer the output and provide a low impedance output which is the average of the two input frequencies. The second amplifier is available for other applications.



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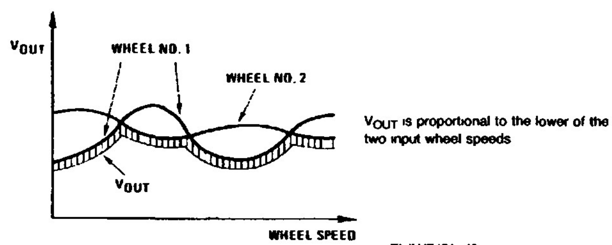

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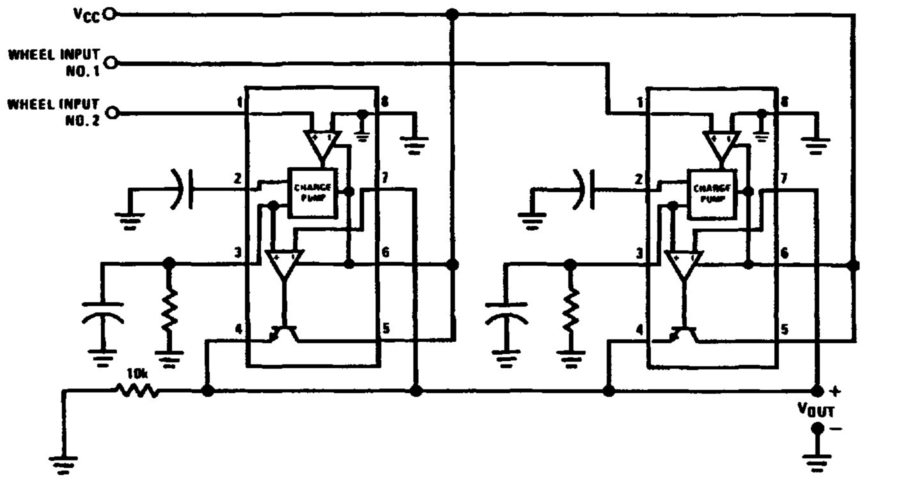
FIGURE 26. "Select-Low" Circuit



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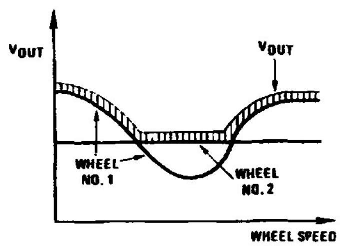

V_{OUT} is proportional to the higher of the two input wheel speeds

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FIGURE 27. "Select-High" Circuit

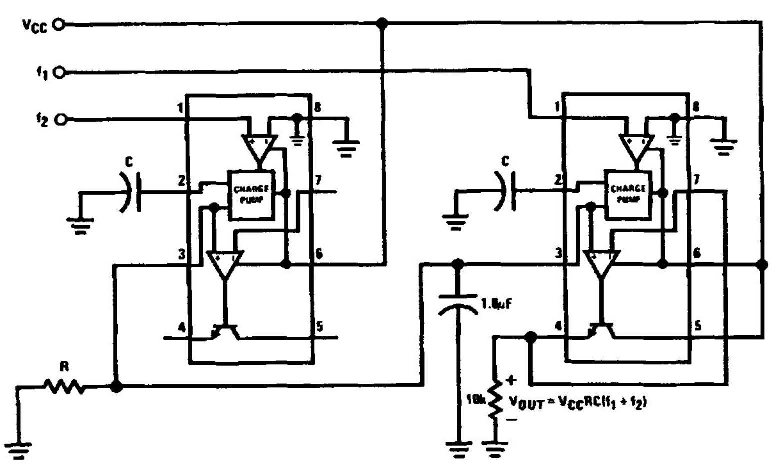

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FIGURE 28. "Select-Average" Circuit

Transmission and Clutch Control Functions

Electric clutches can be added to automotive transmissions to eliminate the 6% slip which typically occurs during cruise and which results in a 6% loss in fuel economy. These devices could be operated by a pair of LM2907's as illustrated in *Figure 29*. Magnetic pickups are connected to input and output shafts of the transmission respectively and provide frequency inputs f_1 and f_2 to the circuit. Frequency, f_2, being the output shaft speed, is also a measure of vehicle road speed. Thus the LM2907-8 No. 2 provides a voltage proportional to road speed at pin 3. This is buffered by the op amp in LM2907-8 No. 1 to provide a speed output V_{OUT1} on pin 4. The input shaft provides charge pulses at the rate of $2f_1$ into the inverting node of op amp 2. This node has the integrating network R1, C3 going back to the output of the op amp so that the charge pulses are integrated and provide an inverted output voltage proportional to the input speed. Thus the output V_{OUT2} is proportional to the difference between the two input frequencies. With these two signals—the road speed and the difference between road speed and input shaft speed—it is possible to develop a number of control functions including the electronic clutch and a complete electronic transmission control. (In the configuration shown, it is not possible for V_{OUT2} to go below zero so that there is a limitation to the output swing in this direction. This may be overcome by returning R3 to a negative bias supply instead of to ground.)

CONCLUSION

The applications presented in this note indicate that the LM2907, LM2917 series devices offer a wide variety of uses ranging from very simple low cost frequency to voltage conversion to complex systems building blocks. It is hoped that the ideas contained here have given suggestions which may help provide new solutions to old problems. Additional applications ideas are included in the data sheet, which should be referred to for all specifications and characteristics.

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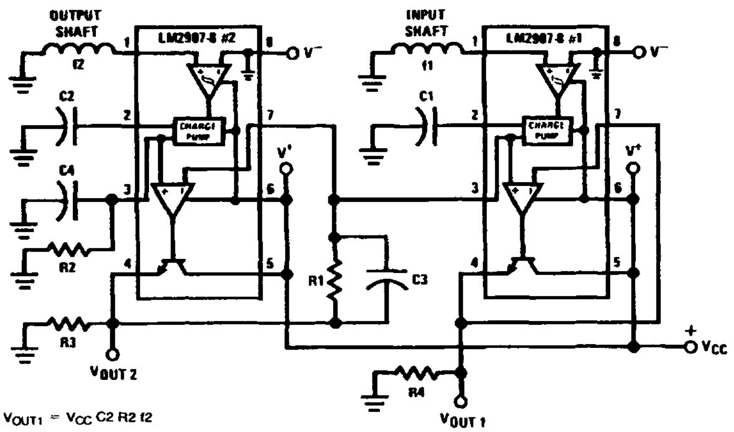
1. Society of Automotive Engineers: Preliminary Recommended Environmental Practices for Electronic Equipment Design. October 1974.
2. See for example: Pollution Control Installers Handbook—California Bureau of Automotive Repair No. BAR H-001 § 5.5.4 NOX control systems.
3. TRW Globe Motors, 2275 Stanley Avenue, Dayton, Ohio 45404.
4. S.A.E. Paper #760018 Air Flow Measurement for Engine Control—Robert D. Joy.
5. Code of Federal Regulations. Title 49 Transportation; Chapter V—National Highway Traffic Safety Administration, Dept. of Transportation; Part 571—Federal Motor Vehicle Safety Standards; Standard No. 121.



$V_{OUT1} = V_{CC}\ C2\ R2\ f2$

$V_{OUT2} = V_{CC}\ (C2\ R2\ f2 - C1\ R1\ f1)$

TL/H/7451-52

FIGURE 29. Transmission or Clutch Control Functions

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

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DUAL D-TYPE POSITIVE-EDGE-TRIGGERED FLIP-FLOPS WITH PRESET AND CLEAR

SDLS119 – DECEMBER 1983 – REVISED MARCH 1988

- **Package Options Include Plastic "Small Outline" Packages, Ceramic Chip Carriers and Flat Packages, and Plastic and Ceramic DIPs**
- **Dependable Texas Instruments Quality and Reliability**

description

These devices contain two independent D-type positive-edge-triggered flip-flops. A low level at the preset or clear inputs sets or resets the outputs regardless of the levels of the other inputs. When preset and clear are inactive (high), data at the D input meeting the setup time requirements are transferred to the outputs on the positive-going edge of the clock pulse. Clock triggering occurs at a voltage level and is not directly related to the rise time of the clock pulse. Following the hold time interval, data at the D input may be changed without affecting the levels at the outputs.

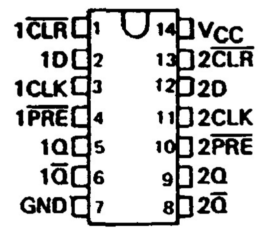
The SN54' family is characterized for operation over the full military temperature range of −55°C to 125°C. The SN74' family is characterized for operation from 0°C to 70°C.

FUNCTION TABLE

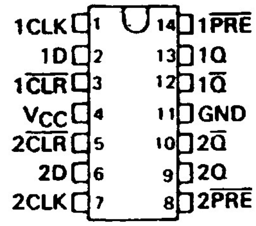
INPUTS				OUTPUTS	
$\overline{PRE}$	$\overline{CLR}$	CLK	D	Q	$\overline{Q}$
L	H	X	X	H	L
H	L	X	X	L	H
L	L	X	X	H†	H†
H	H	↑	H	H	L
H	H	↑	L	L	H
H	H	L	X	Q_0	$\overline{Q}_0$

† The output levels in this configuration are not guaranteed to meet the minimum levels in V_{OH} if the lows at preset and clear are near V_{IL} maximum. Furthermore, this configuration is nonstable; that is, it will not persist when either preset or clear returns to its inactive (high) level.

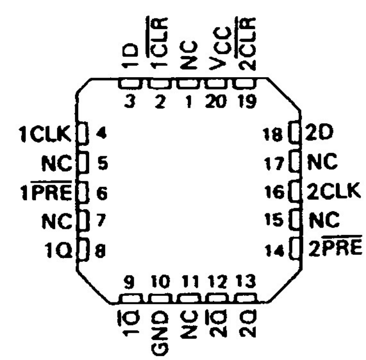
SN5474 . . . J PACKAGE
SN54LS74A, SN54S74 . . . J OR W PACKAGE
SN7474 . . . N PACKAGE
SN74LS74A, SN74S74 . . . D OR N PACKAGE
(TOP VIEW)



SN5474 . . . W PACKAGE
(TOP VIEW)

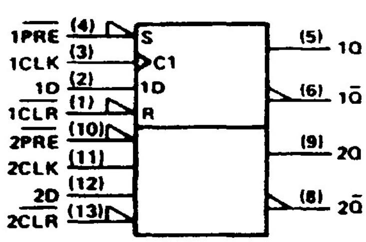


SN54LS74A, SN54S74 . . . FK PACKAGE
(TOP VIEW)



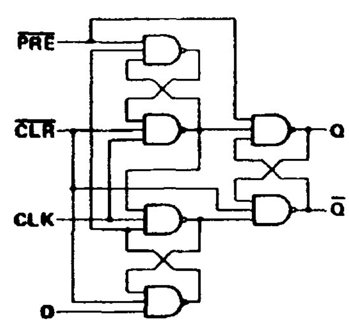
NC - No internal connection

logic symbol‡



‡This symbol is in accordance with ANSI/IEEE Std 91-1984 and IEC Publication 617-12.
Pin numbers shown are for D, J, N, and W packages.

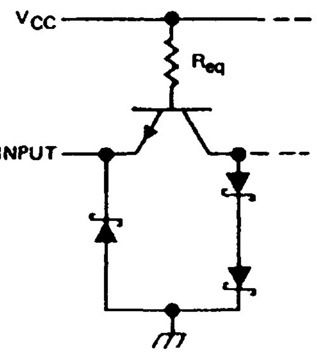
logic diagram (positive logic)



schematics of inputs and outputs

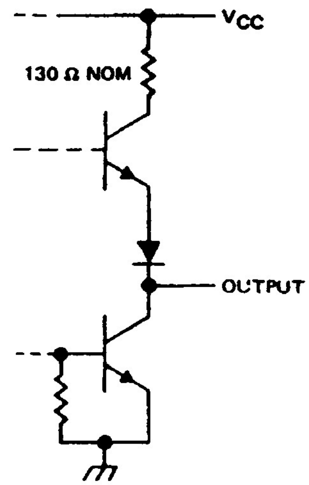
'74

EQUIVALENT OF EACH INPUT



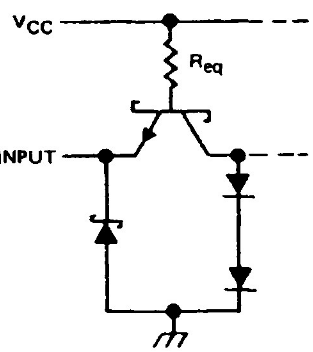
I_{IL} MAX	R_{eq} NOM
−1.6 mA	4 kΩ
−3.2 mA	2 kΩ

TYPICAL OF ALL OUTPUTS



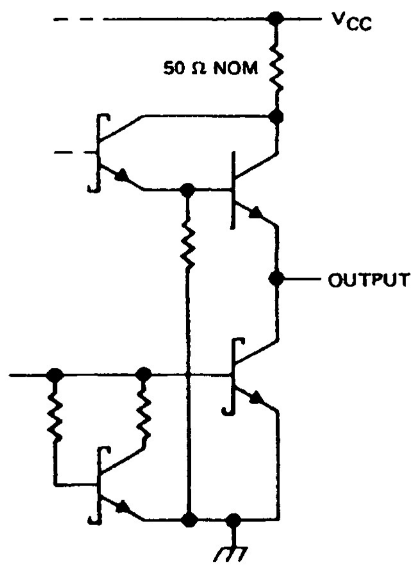
'S74

EQUIVALENT OF EACH INPUT



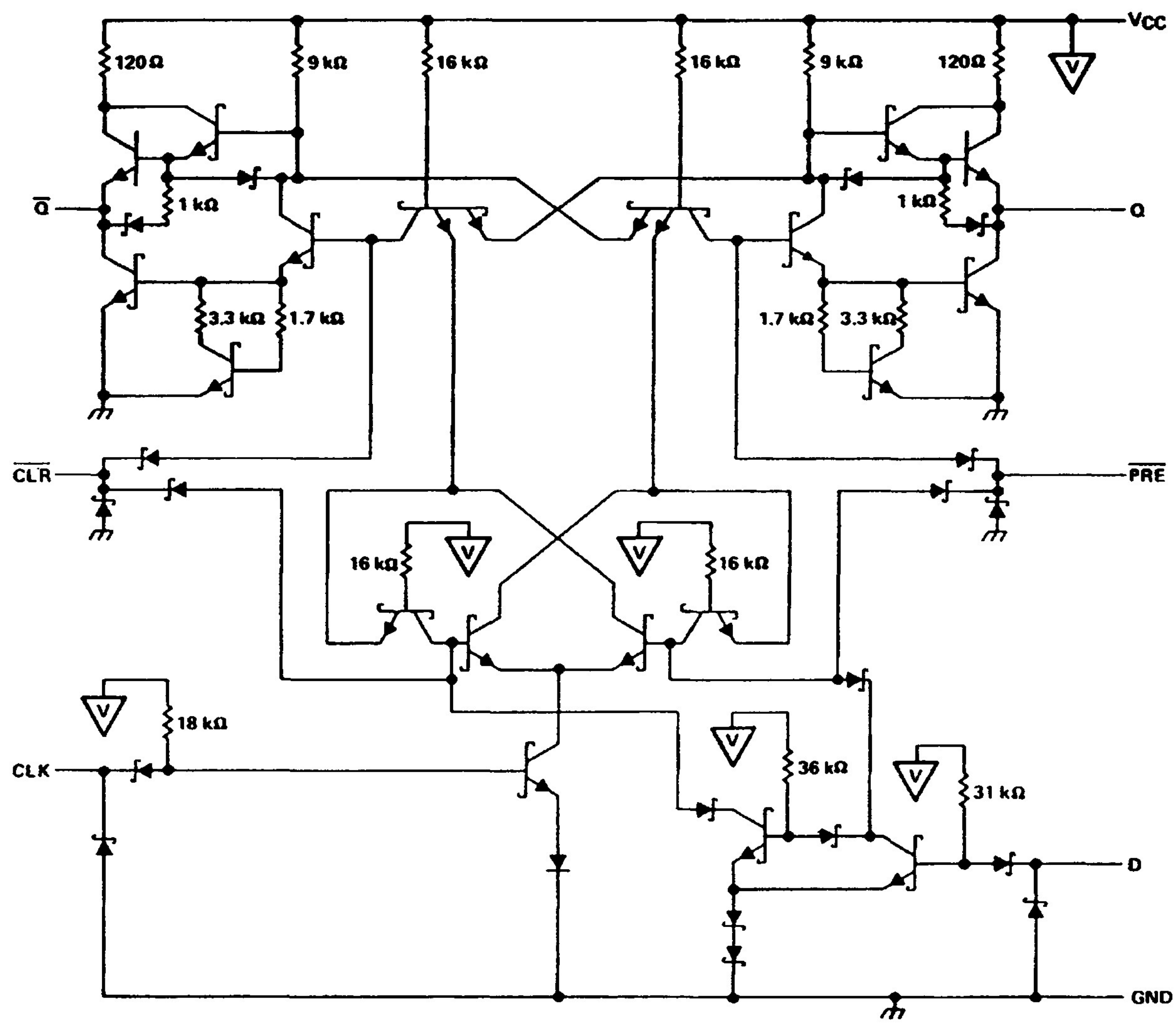
I_{IL} MAX	R_{eq} NOM
−2 mA	2.8 kΩ
−4 mA	1.4 kΩ
−6 mA	940 Ω

TYPICAL OF ALL OUTPUTS



schematic

'LS74A



absolute maximum ratings over operating free-air temperature range (unless otherwise noted)

Supply voltage, V_{CC} (see Note 1)		7 V
Input voltage:	'74, 'S74	5.5 V
	'LS74A	7 V
Operating free-air temperature range:	SN54'	−55°C to 125°C
	SN74'	0°C to 70°C
Storage temperature range		−65°C to 150°C

NOTE 1: Voltage values are with respect to network ground terminal.

recommended operating conditions

			SN5474 MIN	SN5474 NOM	SN5474 MAX	SN7474 MIN	SN7474 NOM	SN7474 MAX	UNIT
V_{CC}	Supply voltage		4.5	5	5.5	4.75	5	5.25	V
V_{IH}	High-level input voltage		2			2			V
V_{IL}	Low-level input voltage				0.8			0.8	V
I_{OH}	High-level output current				−0.4			−0.4	mA
I_{OL}	Low-level output current				16			16	mA
t_w	Pulse duration	CLK high	30			30			ns
		CLK low	37			37			ns
		$\overline{PRE}$ or $\overline{CLR}$ low	30			30			ns
t_{su}	Input setup time before CLK↑		20			20			ns
t_h	Input hold time-data after CLK↑		5			5			ns
T_A	Operating free-air temperature		−55		125	0		70	°C

electrical characteristics over recommended operating free-air temperature range (unless otherwise noted)

PARAMETER		TEST CONDITIONS†	SN5474 MIN	SN5474 TYP‡	SN5474 MAX	SN7474 MIN	SN7474 TYP‡	SN7474 MAX	UNIT
V_{IK}		V_{CC} = MIN, I_I = −12 mA			−1.5			−1.5	V
V_{OH}		V_{CC} = MIN, V_{IH} = 2 V, V_{IL} = 0.8 V, I_{OH} = −0.4 mA	2.4	3.4		2.4	3.4		V
V_{OL}		V_{CC} = MIN, V_{IH} = 2 V, V_{IL} = 0.8 V, I_{OL} = 16 mA		0.2	0.4		0.2	0.4	V
I_I		V_{CC} = MAX, V_I = 5.5 V			1			1	mA
I_{IH}	D	V_{CC} = MAX, V_I = 2.4 V			40			40	μA
	$\overline{CLR}$				120			120	
	All Other				80			80	
I_{IL}	D	V_{CC} = MAX, V_I = 0.4 V			−1.6			−1.6	mA
	$\overline{PRE}$§				−1.6			−1.6	
	$\overline{CLR}$§				−3.2			−3.2	
	CLK				−3.2			−3.2	
I_{OS}¶		V_{CC} = MAX	−20		−57	−18		−57	mA
I_{CC}#		V_{CC} = MAX, See Note 2		8.5	15		8.5	15	mA

†For conditions shown as MIN or MAX, use the appropriate value specified under recommended operating conditions.
‡All typical values are at V_{CC} = 5 V, T_A = 25°C.
§Clear is tested with preset high and preset is tested with clear high.
¶Not more than one output should be shown at a time.
#Average per flip-flop.
NOTE 2: With all outputs open, I_{CC} is measured with the Q and $\overline{Q}$ outputs high in turn. At the time of measurement, the clock input is grounded.

switching charateristics, V_{CC} = 5 V, T_A = 25°C (see note 3)

PARAMETER	FROM (INPUT)	TO (OUTPUT)	TEST CONDITIONS	MIN	TYP	MAX	UNIT
f_{max}			R_L = 400 Ω, C_L = 15 pF	15	25		MHz
t_{PLH}	$\overline{PRE}$ or $\overline{CLR}$	Q or $\overline{Q}$				25	ns
t_{PHL}						40	ns
t_{PLH}	CLK	Q or $\overline{Q}$			14	25	ns
t_{PHL}					20	40	ns

NOTE 3: Load circuits and voltage waveforms are shown in Section 1.

recommended operating conditions

			SN54LS74A			SN74LS74A			UNIT
			MIN	NOM	MAX	MIN	NOM	MAX	
V_{CC}	Supply voltage		4.5	5	5.5	4.75	5	5.25	V
V_{IH}	High-level input voltage		2			2			V
V_{IL}	Low-level input voltage				0.7			0.8	V
I_{OH}	High-level output current				−0.4			−0.4	mA
I_{OL}	Low-level output current				4			8	mA
f_{clock}	Clock frequency		0		25	0		25	MHz
t_w	Pulse duration	CLK high	25			25			ns
		$\overline{PRE}$ or $\overline{CLR}$ low	25			25			
t_{su}	Setup time-before CLK↑	High-level data	20			20			ns
		Low-level data	20			20			
t_h	Hold time-data after CLK↑		5			5			ns
T_A	Operating free-air temperature		−55		125	0		70	°C

electrical characteristics over recommended operating free-air temperature range (unless otherwise noted)

PARAMETER		TEST CONDITIONS†	SN54LS74A			SN74LS74A			UNIT
			MIN	TYP‡	MAX	MIN	TYP‡	MAX	
V_{IK}		V_{CC} = MIN, I_I = −18 mA			−1.5			−1.5	V
V_{OH}		V_{CC} = MIN, V_{IH} = 2 V, V_{IL} = MAX, I_{OH} = −0.4 mA	2.5	3.4		2.7	3.4		V
V_{OL}		V_{CC} = MIN, V_{IL} = MAX, V_{IH} = 2 V, I_{OL} = 4 mA		0.25	0.4		0.25	0.4	V
		V_{CC} = MIN, V_{IL} = MAX, V_{IH} = 2 V, I_{OL} = 8 mA					0.35	0.5	
I_I	D or CLK	V_{CC} = MAX, V_I = 7 V			0.1			0.1	mA
	$\overline{CLR}$ or $\overline{PRE}$				0.2			0.2	
I_{IH}	D or CLK	V_{CC} = MAX, V_I = 2.7 V			20			20	μA
	$\overline{CLR}$ or $\overline{PRE}$				40			40	
I_{IL}	D or CLK	V_{CC} = MAX, V_I = 0.4 V			−0.4			−0.4	mA
	$\overline{CLR}$ or $\overline{PRE}$				−0.8			−0.8	
I_{OS}§		V_{CC} = MAX, See Note 4	−20		−100	−20		−100	mA
I_{CC} (Total)		V_{CC} = MAX, See Note 2		4	8		4	8	mA

† For conditions shown as MIN or MAX, use the appropriate value specified under recommended operating conditions.
‡ All typical values are at V_{CC} = 5 V, T_A = 25°C.
§ Not more than one output should be shorted at a time, and the duration of the short circuit should not exceed one second.
NOTE 2: With all outputs open, I_{CC} is measured with the Q and $\overline{Q}$ outputs high in turn. At the time of measurement, the clock input is grounded.
NOTE 4: For certain devices where state commutation can be caused by shorting an output to ground, an equivalent test may be performed with V_O = 2.25 V and 2.125 V for the 54 family and the 74 family, respectively, with the minimum and maximum limits reduced to one half of their stated values.

switching characteristics, V_{CC} = 5 V, T_A = 25°C (see note 3)

PARAMETER	FROM (INPUT)	TO (OUTPUT)	TEST CONDITIONS	MIN	TYP	MAX	UNIT
f_{max}			R_L = 2 kΩ, C_L = 15 pF	25	33		MHz
t_{PLH}	$\overline{CLR}$, $\overline{PRE}$ or CLK	Q or $\overline{Q}$			13	25	ns
t_{PHL}					25	40	ns

Note 3: Load circuits and voltage waveforms are shown in Section 1.

recommended operating conditions

			SN54S74 MIN	SN54S74 NOM	SN54S74 MAX	SN74S74 MIN	SN74S74 NOM	SN74S74 MAX	UNIT
V_{CC}	Supply voltage		4.5	5	5.5	4.75	5	5.25	V
V_{IH}	High-level input voltage		2			2			V
V_{IL}	Low-level input voltage				0.8			0.8	V
I_{OH}	High-level output current				−1			−1	mA
I_{OL}	Low-level output current				20			20	mA
t_w	Pulse duration	CLK high	6			6			ns
		CLK low	7.3			7.3			
		$\overline{CLR}$ or $\overline{PRE}$ low	7			7			
t_{su}	Setup time, before CLK↑	High-level data	3			3			ns
		Low-level data	3			3			
t_h	Input hold time - data after CLK↑		2			2			ns
T_A	Operating free-air temperature		−55		125	0		70	°C

electrical characteristics over recommended operating free-air temperature range (unless otherwise noted)

PARAMETER		TEST CONDITIONS†	SN54S74 MIN	SN54S74 TYP‡	SN54S74 MAX	SN74S74 MIN	SN74S74 TYP‡	SN74S74 MAX	UNIT
V_{IK}		V_{CC} = MIN, I_I = −18 mA,			−1.2			−1.2	V
V_{OH}		V_{CC} = MIN, V_{IH} = 2 V, V_{IL} = 0.8 V, I_{OH} = −1 mA	2.5	3.4		2.7	3.4		V
V_{OL}		V_{CC} = MIN, V_{IH} = 2 V, V_{IL} = 0.8 V, I_{OL} = 20 mA			0.5			0.5	V
I_I		V_{CC} = MAX, V_I = 5.5 V			1			1	mA
I_{IH}	D	V_{CC} = MAX, V_I = 2.7 V			50			50	µA
	$\overline{CLR}$				150			150	
	$\overline{PRE}$ or CLK				100			100	
I_{IL}	D	V_{CC} = MAX, V_I = 0.5 V			−2			−2	mA
	$\overline{CLR}$¶				−6			−6	
	$\overline{PRE}$¶				−4			−4	
	CLK				−4			−4	
I_{OS}§		V_{CC} = MAX	−40		−100	−40		−100	mA
I_{CC}#		V_{CC} = MAX, See Note 2		15	25		15	25	mA

†For conditions shown as MIN or MAX, use the appropriate value specified under recommended operating conditions.
‡All typical values are at V_{CC} = 5 V, T_A = 25°C.
§Not more than one output should be shorted at a time, and the duration of the short circuit should not exceed one second.
¶Clear is tested with preset high and preset is tested with clear high.
#Average per flip-flop.
NOTE 2: With all outputs open, I_{CC} is measured with the Q and $\overline{Q}$ outputs high in turn. At the time of measurement, the clock input is grounded.

switching characteristics, V_{CC} = 5 V, T_A = 25°C (see note 3)

PARAMETER	FROM (INPUT)	TO (OUTPUT)	TEST CONDITIONS	MIN	TYP	MAX	UNIT
f_{max}			R_L = 280 Ω, C_L = 15 pF	75	110		MHz
t_{PLH}	$\overline{PRE}$ or $\overline{CLR}$	Q or $\overline{Q}$			4	6	ns
t_{PHL}	$\overline{PRE}$ or $\overline{CLR}$ (CLK high)	$\overline{Q}$ or Q			9	13.5	ns
	$\overline{PRE}$ or $\overline{CLR}$ (CLK low)				5	8	
t_{PLH}	CLK	Q or $\overline{Q}$			6	9	ns
t_{PHL}					6	9	ns

NOTE 3: Load circuits and voltage waveforms are shown in Section 1.

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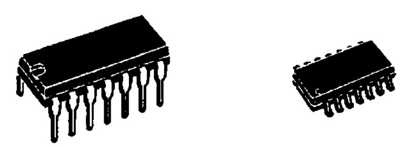
LM124A
LM224A - LM324A

LOW POWER QUAD OPERATIONAL AMPLIFIERS

- WIDE GAIN BANDWDTH / 1.3MHz
- LARGE VOLTAGE GAIN : 100dB
- VERY LOW SUPPLY CURRENT/AMPLI : 375µA
- LOW INPUT BIAS CURRENT : 20nA
- LOW INPUT OFFSET VOLTAGE : 3mV max.
- LOW INPUT OFFSET CURRENT : 2nA
- WIDE POWER SUPPLY RANGE :
  SINGLE SUPPLY : +3V TO +30V
  DUAL SUPPLIES : ±1.5V TO ±15V
- INPUT COMMON-MODE VOLTAGE RANGE INCLUDES GROUND
- ESD INTERNAL PROTECTION : 2kV



N
DIP14
(Plastic Package)

D
SO14
(Plastic Micropackage)

DESCRIPTION

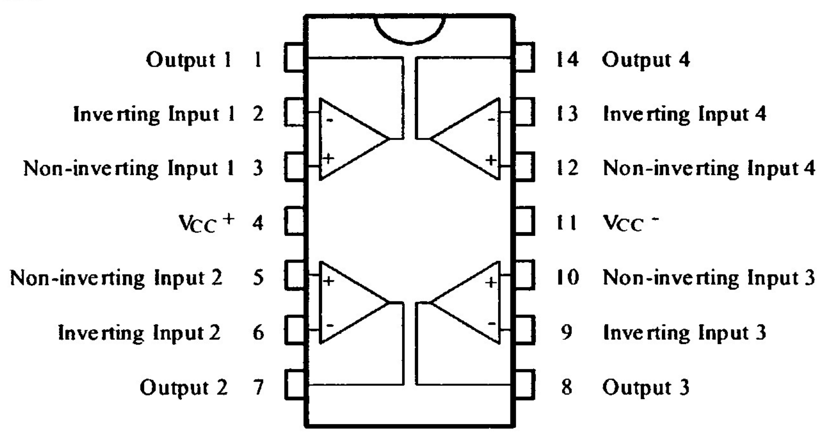
These circuits consist of four independent, high gain, internally frequency compensated operational amplifiers. They operate from a single power supply over a wide range of voltages. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage.

All the pins are protected against electrostatic discharges up to 2000V (as a consequence, the input voltages must not exceed the magnitude of V_{CC}^{+} or V_{CC}^{-}.)

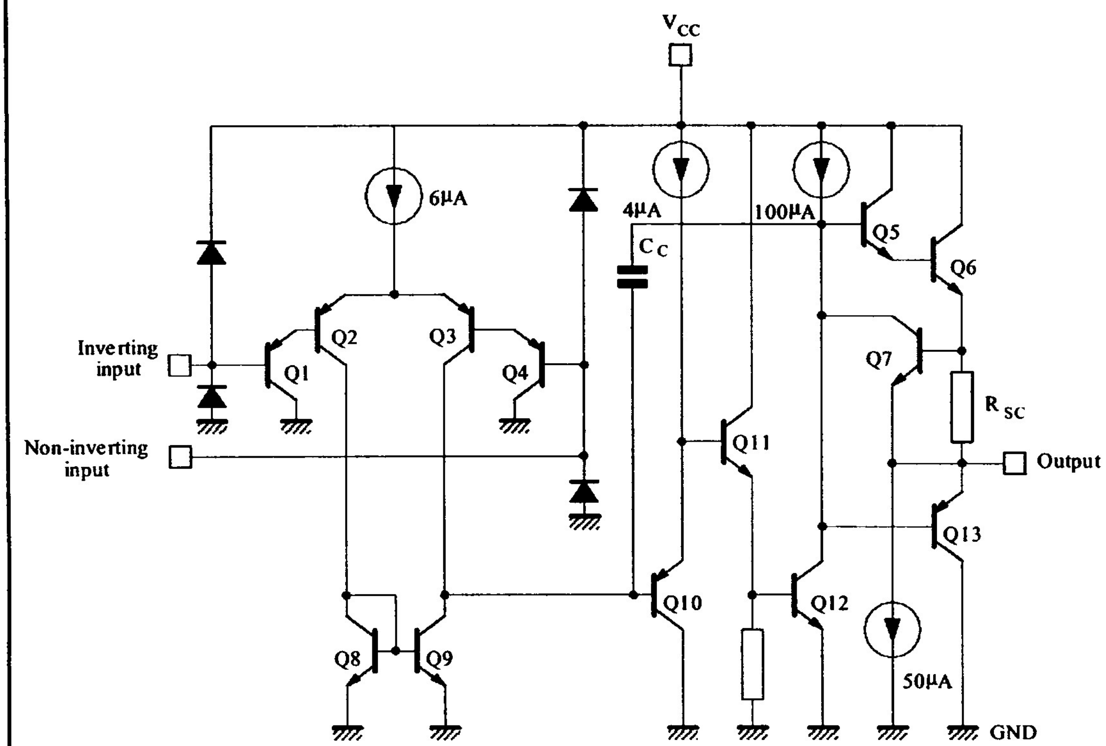
ORDER CODES

Part Number	Temperature Range	Package	
		N	D
LM124A	-55°C, +125°C	•	•
LM224A	-40°C, +105°C	•	•
LM324A	0°C, +70°C	•	•
Example : LM224AN			

PIN CONNECTIONS (top view)



SCHEMATIC DIAGRAM (1/4 LM124A)



ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter	LM124A	LM224A	LM324A	Unit
V_{cc}	Supply Voltage	±16 or 32			V
V_i	Input Voltage	-0.3 to +32			V
V_{id}	Differential Input Voltage - (*)	+32	+32	+32	V
P_{tot}	Power Dissipation N Suffix D Suffix	500 -	500 400	500 400	mW mW
-	Output Short-circuit Duration - (note 1)	Infinite			
I_{in}	Input Current – (note 6)	50	50	50	mA
T_{oper}	Operating Free Air Temperature Range	-55 to +125	-40 to +105	0 to +70	°C
T_{stg}	Storage Temperature Range	-65 to +150	-65 to +150	-65 to +150	°C

(*) - Either or both input voltages must not exceed the magnitude of V_{CC}^+ or V_{CC}^-.

SGS-THOMSON MICROELECTRONICS

ELECTRICAL CHARACTERISTICS

V_{CC}^{+} = +5V, V_{CC}^{-} = Ground, V_O = 1.4V, T_{amb} = +25°C (unless otherwise specified)

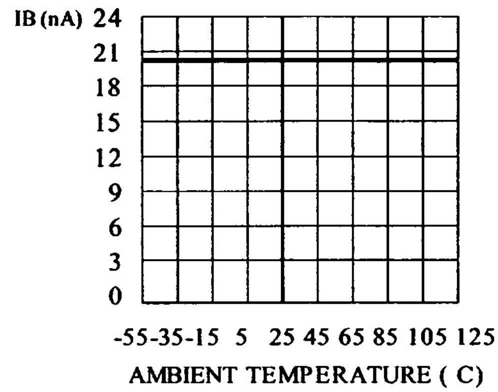
Symbol	Parameter	LM124A - LM224A - LM324A Min.	Typ.	Max.	Unit
V_{io}	Input Offset Voltage (note 3) T_{amb} = +25°C $T_{min.} \leq T_{amb} \leq T_{max.}$		2	3 5	mV
I_{io}	Input Offset Current T_{amb} = +25°C $T_{min.} \leq T_{amb} \leq T_{max.}$		2	20 40	nA
I_{ib}	Input Bias Current (note 2) T_{amb} = +25°C $T_{min.} \leq T_{amb} \leq T_{max.}$		20	100 200	nA
A_{vd}	Large Signal Voltage Gain (V_{CC}^{+} = +15V, R_L = 2kΩ, V_O = 1.4V to 11.4V) T_{amb} = +25°C $T_{min.} \leq T_{amb} \leq T_{max.}$	50 25	100		V/mV
SVR	Supply Voltage Rejection Ratio ($R_S \leq$ 10kΩ) (V_{CC}^{+} = 5V to 30V) T_{amb} = +25°C $T_{min.} \leq T_{amb} \leq T_{max.}$	65 65	110		dB
I_{CC}	Supply Current, all Amp, no load T_{amb} = +25°C V_{CC} = +5V V_{CC} = +30V $T_{min.} \leq T_{amb} \leq T_{max.}$ V_{CC} = +5V V_{CC} = +30V		0.7 1.5 0.8 1.5	1.2 3 1.2 3	mA
V_{icm}	Input Common Mode Voltage Range (V_{CC} = +30V) - (note 4) T_{amb} = +25°C $T_{min.} \leq T_{amb} \leq T_{max.}$	0 0		V_{CC} -1.5 V_{CC} -2	V
CMR	Common-mode Rejection Ratio ($R_S \leq$ 10kΩ) T_{amb} = +25°C $T_{min.} \leq T_{amb} \leq T_{max}$	70 60	80		dB
I_{source}	Output Current Source (V_{id} = +1V) V_{CC} = +15V, V_o = +2V	20	40	70	mA
I_{sink}	Output Sink Current (V_{id} = -1V) V_{CC} = +15V, V_o = +2V V_{CC} = +15V, V_o = +0.2V	10 12	20 50		mA µA

ELECTRICAL CHARACTERISTICS (continued)

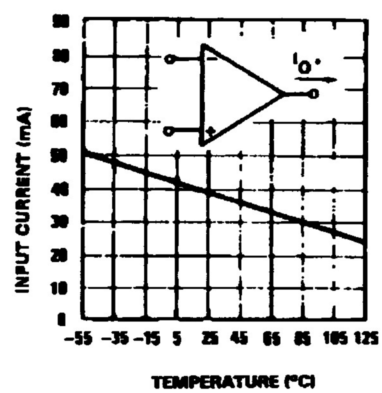
Symbol	Parameter	LM124A - LM224A - LM324A Min.	Typ.	Max.	Unit
V_{OH}	High Level Output Voltage (V_{CC} = +30V) T_{amb} = +25°C R_L = 2kΩ $T_{min.} \leq T_{amb} \leq T_{max.}$ T_{amb} = +25°C R_L = 10kΩ $T_{min.} \leq T_{amb} \leq T_{max.}$ (V_{CC} = +5V, R_L = 2kΩ) T_{amb} = +25°C $T_{min.} \leq T_{amb} \leq T_{max.}$	26 26 27 27 3.5 3	27 28		V
V_{OL}	Low Level Output Voltage (R_L = 10kΩ) T_{amb} = +25°C $T_{min.} \leq T_{amb} \leq T_{max.}$		5	20 20	mV
SR	Slew Rate (V_{CC} = 15V, V_I = 0.5 to 3V, R_L = 2kΩ, C_L = 100pF, unity gain)		0.4		V/µs
GBP	Gain Bandwidth Product (V_{CC} = 30V f = 100kHz, V_{in} = 10mV R_L = 2kΩ, C_L = 100pF)		1.3		MHz
THD	Total Harmonic Distortion (f = 1kHz, A_V = 20dB, R_L = 2kΩ, V_O = $2V_{pp}$ C_L = 100pF, V_{CC} = 30V)		0.015		%
e_n	Equivalent Input Noise Voltage (f = 1kHz, R_s = 100Ω, V_{CC} = 30V)		40		$\frac{nV}{\sqrt{Hz}}$
DV_{io}	Input Offset Voltage Drift		7	30	µV/°C
DI_{IO}	Input Offset Current Drift		10	200	pA/°C
V_{O1}/V_{O2}	Channel Separation (note 5) 1kHz ≤ f ≤ 20kHz		120		dB

Notes :
1. Short-circuits from the output to V_{CC} can cause excessive heating if V_{CC} > 15V. The maximum output current is approximately 40mA independent of the magnitude of V_{CC}. Destructive dissipation can result from simultaneous short-circuit on all amplifiers.
2. The direction of the input current is out of the IC. This current is essentially constant, independent of the state of the output so no loading change exists on the input lines.
3. V_o = 1.4V, R_s = 0Ω, 5V < V_{CC}^+ < 30V, 0 < V_{ic} < V_{CC}^+ - 1.5V
4. The input common-mode voltage of either input signal voltage should not be allowed to go negative by more than 0.3V. The upper end of the common-mode voltage range is V_{CC}^+ - 1.5V, but either or both inputs can go to +32V without damage.
5. Due to the proximity of external components insure that coupling is not originating via stray capacitance between these external parts. This typically can be detected as this type of capacitance increases at higher frequences.
6. This input current only exists when the voltage at any of the input leads is driven negative. It is due to the collector-base junction of the input PNP transistor becoming forward biased and thereby acting as input diodes clamps. In addition to this diode action, there is also NPN parasitic action on the IC chip. this transistor action can cause the output voltages of the Op-amps to go to the V_{CC} voltage level (or to ground for a large overdrive) for the time duration than an input is driven negative.
This is not destructive and normal output will set up again for input voltage higher than -0.3V.

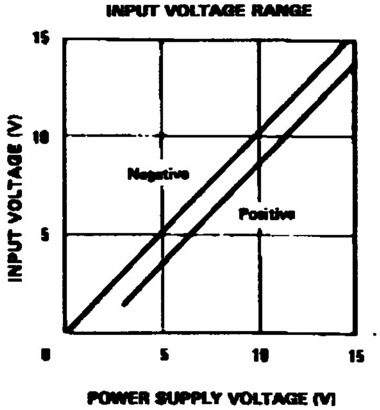
INPUT BIAS CURRENT
versus AMBIENT TEMPERATURE



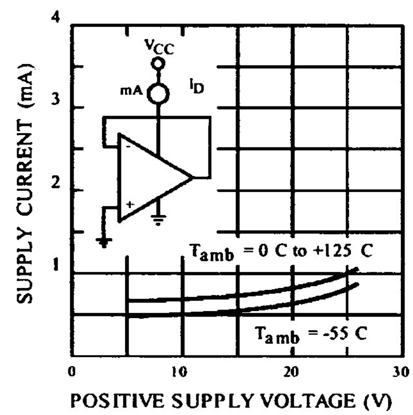
CURRENT LIMITING (Note 6)



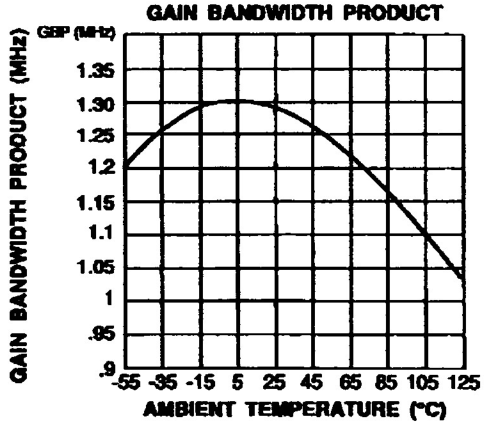
INPUT VOLTAGE RANGE



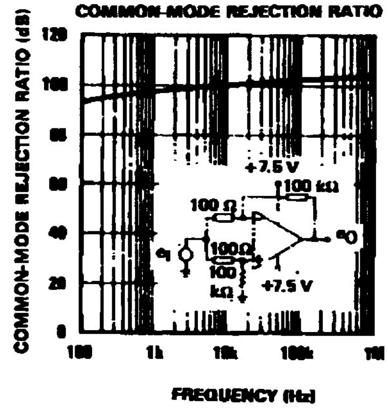
SUPPLY CURRENT



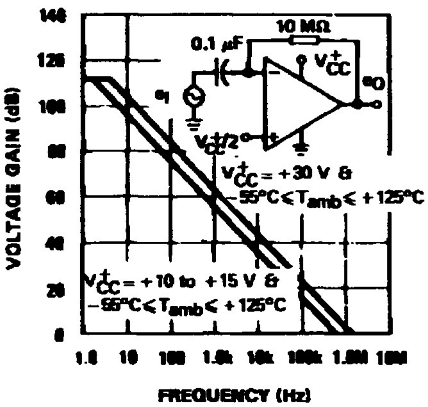
GAIN BANDWIDTH PRODUCT



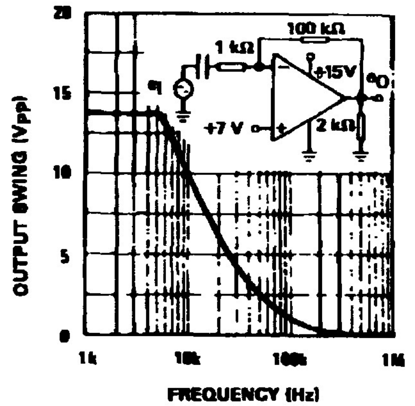
COMMON-MODE REJECTION RATIO



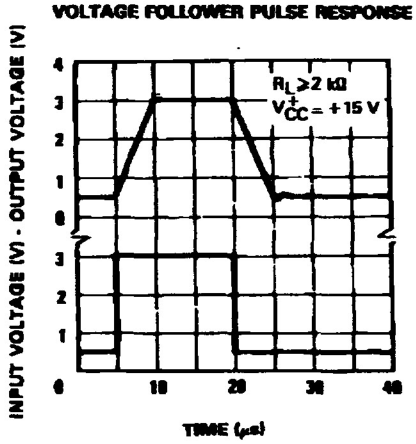
OPEN LOOP FREQUENCY RESPONSE



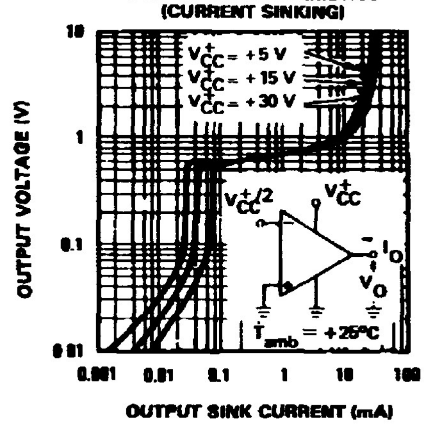
LARGE SIGNAL FREQUENCY RESPONSE



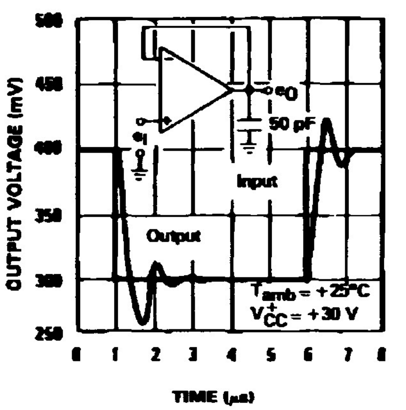
VOLTAGE FOLLOWER PULSE RESPONSE



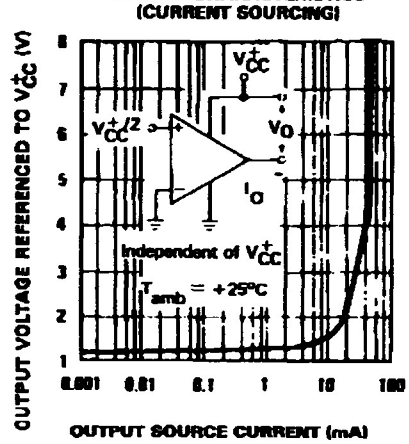
OUTPUT CHARACTERISTICS (CURRENT SINKING)



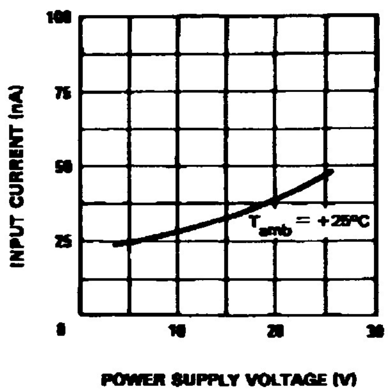
VOLTAGE FOLLOWER PULSE RESPONSE (SMALL SIGNAL)



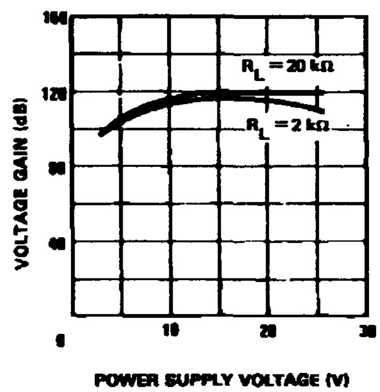
OUTPUT CHARACTERISTICS (CURRENT SOURCING)



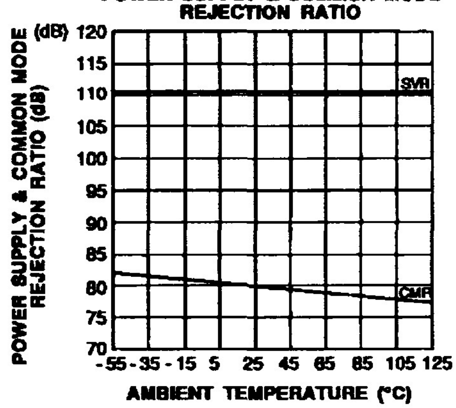
INPUT CURRENT



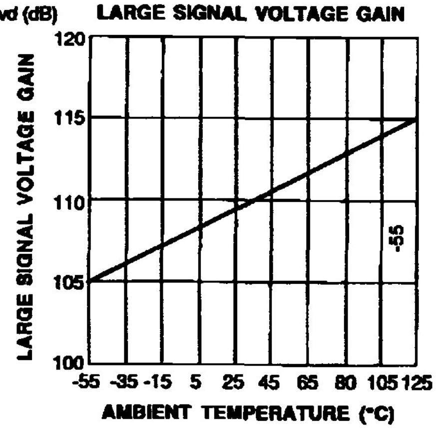
VOLTAGE GAIN



POWER SUPPLY & COMMON MODE REJECTION RATIO

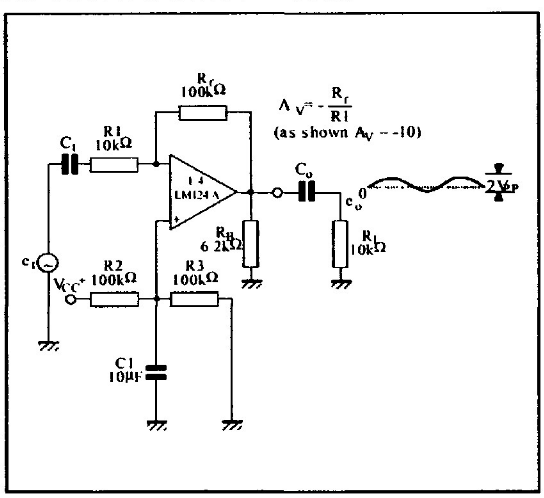


LARGE SIGNAL VOLTAGE GAIN

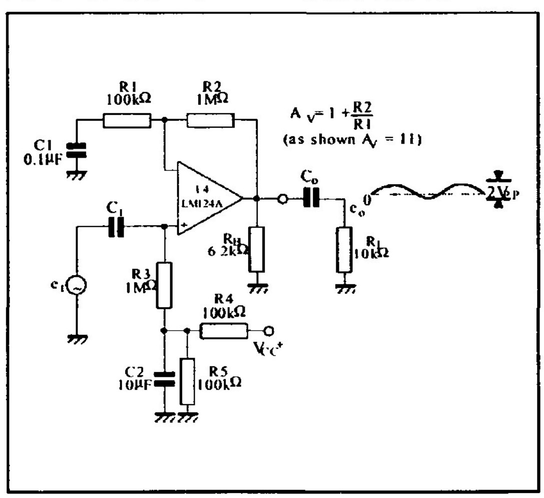


TYPICAL SINGLE - SUPPLY APPLICATIONS

AC COUPLED INVERTING AMPLIFIER

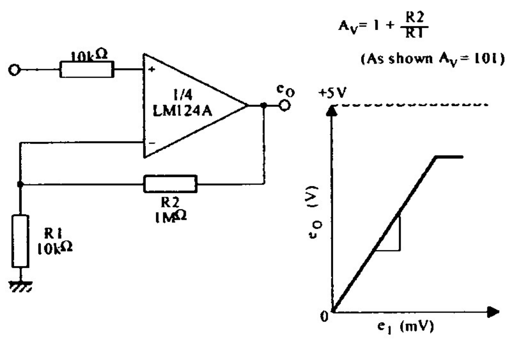


AC COUPLED NON-INVERTING AMPLIFIER

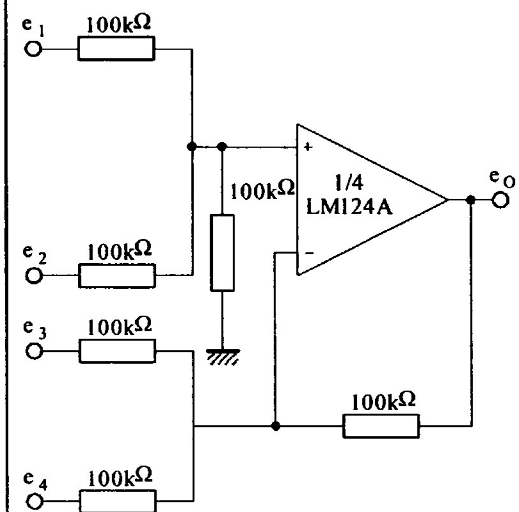


TYPICAL SINGLE - SUPPLY APPLICATIONS

NON-INVERTING DC GAIN

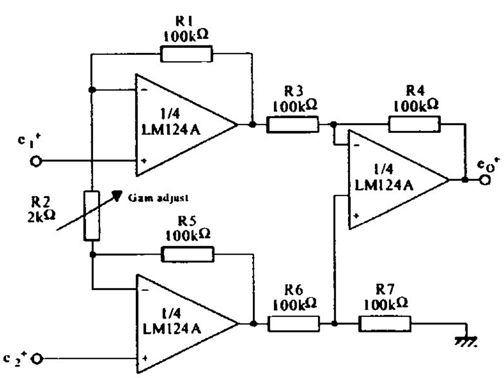


DC SUMMING AMPLIFIER



$e_o = e_1 + e_2 - e_3 - e_4$
where $(e_1 + e_2) \geq (e_3 + e_4)$
to keep $e_o \geq$ 0V

HIGH INPUT Z ADJUSTABLE GAIN DC INSTRUMENTATION AMPLIFIER

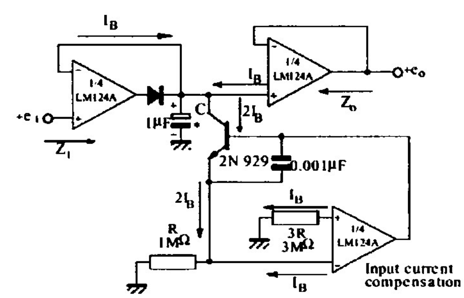


if $R_1 = R_5$ and $R_3 = R_4 = R_6 = R_7$

$e_o = [1 + \frac{2R_1}{R_2}](e_2 - e_1)$

As shown $e_o = 101 (e_2 - e_1)$.

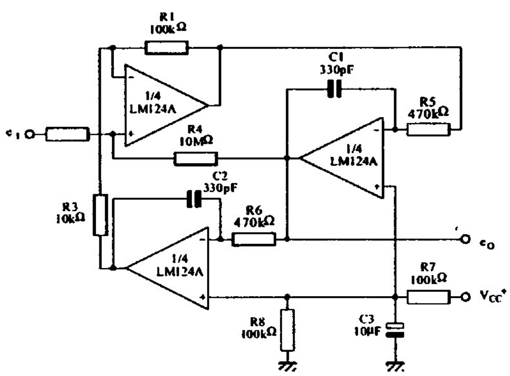
LOW DRIFT PEAK DETECTOR



* Polycarbonate or polyethylene

TYPICAL SINGLE - SUPPLY APPLICATIONS

ACTIVER BANDPASS FILTER



F_O = 1kHz

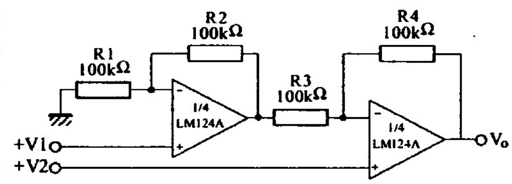
Q = 50

A_V = 100 (40dB)

HIGH INPUT Z, DC DIFFERENTIAL AMPLIFIER

For $\frac{R_1}{R_2} = \frac{R_4}{R_3}$

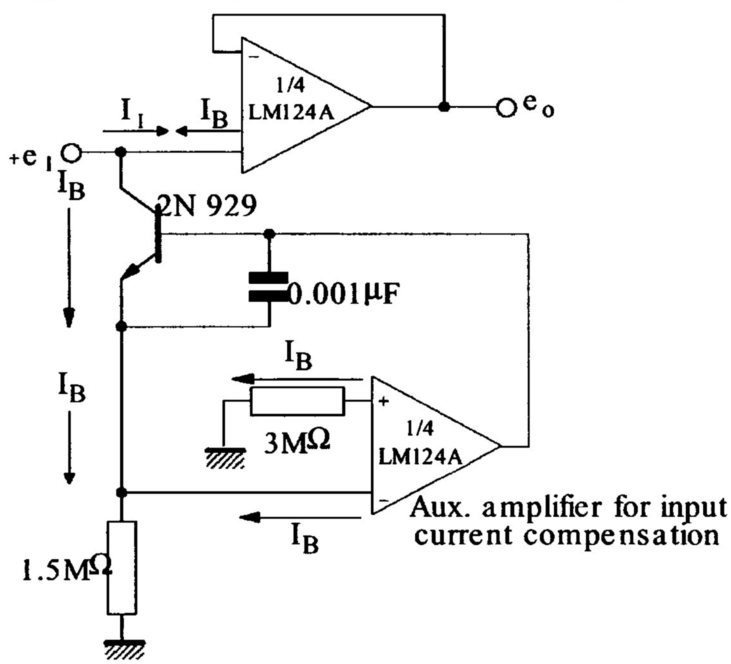
(CMRR depends on this resistor ratio match)



$e_o (1 + \frac{R_4}{R_3}) (e_2 - e_1)$

As shown $e_o = (e_2 - e_1)$

USING SYMMETRICAL AMPLIFIERS TO REDUCE INPUT CURRENT (GENERAL CONCEPT)



- LARGE VOLTAGE GAIN : 100dB
- VERY LOW SUPPLY CURRENT/AMPLI : 375µA
- LOW INPUT BIAS CURRENT : 20nA
- LOW INPUT OFFSET VOLTAGE : 2mV
- LOW INPUT OFFSET CURRENT : 2nA
- WIDE POWER SUPPLY RANGE :
  SINGLE SUPPLY : +3V to +30V
  DUAL SUPPLIES : ±1.5V to ±15V

Applies to : LM124A-LM224A-LM324A

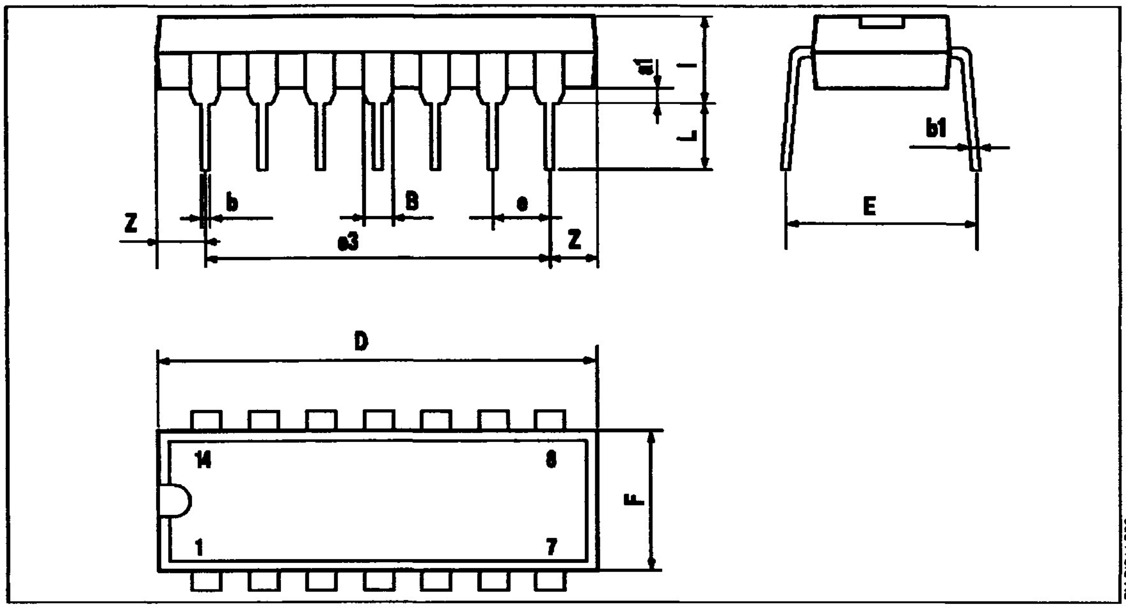
```
** Standard Linear Ics Macromodels, 1993.
** CONNECTIONS :
* 1 INVERTING INPUT
* 2 NON-INVERTING INPUT
* 3 OUTPUT
* 4 POSITIVE POWER SUPPLY
* 5 NEGATIVE POWER SUPPLY

.SUBCKT LM124 1 3 2 4 5 (analog)
***********************************************************
.MODEL MDTH D IS=1E-8 KF=3.104131E-15
CJO=10F
* INPUT STAGE
CIP 2 5 1.000000E-12
CIN 1 5 1.000000E-12
EIP 10 5 2 5 1
EIN 16 5 1 5 1
RIP 10 11 2.600000E+01
RIN 15 16 2.600000E+01
RIS 11 15 2.003862E+02
DIP 11 12 MDTH 400E-12
DIN 15 14 MDTH 400E-12
VOFP 12 13 DC 0
VOFN 13 14 DC 0
IPOL 13 5 1.000000E-05
CPS 11 15 3.783376E-09
DINN 17 13 MDTH 400E-12
VIN 17 5 0.000000e+00
DINR 15 18 MDTH 400E-12
VIP 4 18 2.000000E+00
FCP 4 5 VOFP 3.400000E+01
FCN 5 4 VOFN 3.400000E+01
FIBP 2 5 VOFN 2.000000E-03
FIBN 5 1 VOFP 2.000000E-03
* AMPLIFYING STAGE
FIP 5 19 VOFP 3.600000E+02
FIN 5 19 VOFN 3.600000E+02
RG1 19 5 3.652997E+06
RG2 19 4 3.652997E+06
CC 19 5 6.000000E-09
DOPM 19 22 MDTH 400E-12
DONM 21 19 MDTH 400E-12
HOPM 22 28 VOUT 7.500000E+03
VIPM 28 4 1.500000E+02
HONM 21 27 VOUT 7.500000E+03
VINM 5 27 1.500000E+02
EOUT 26 23 19 5 1
VOUT 23 5 0
ROUT 26 3 20
COUT 3 5 1.000000E-12
DOP 19 25 MDTH 400E-12
VOP 4 25 2.242230E+00
DON 24 19 MDTH 400E-12
VON 24 5 7.922301E-01
.ENDS
```

ELECTRICAL CHARACTERISTICS
$V_{CC}^{+} = +5V$, $V_{CC}^{-} = 0V$, $T_{amb} = 25^{o}C$ (unless otherwise specified)

Symbol	Conditions	Value	Unit
V_{io}		0	mV
A_{vd}	$R_L = 2k\Omega$	100	V/mV
I_{CC}	No load, per operator	350	µA
V_{icm}		-15 to +13.5	V
V_{OH}	$R_L = 2k\Omega$ ($V_{CC}^{+} = 15V$)	+13.5	V
V_{OL}	RL = 10kΩ	5	mV
I_{OS}	$V_O = +2V$, $V_{CC} = +15V$	+40	mA
GBP	$R_L = 2k\Omega$, $C_L = 100pF$	1.3	MHz
SR	$R_L = 2k\Omega$, $C_L = 100pF$	0.4	V/µs

PACKAGE MECHANICAL DATA

14 PINS - PLASTIC DIP



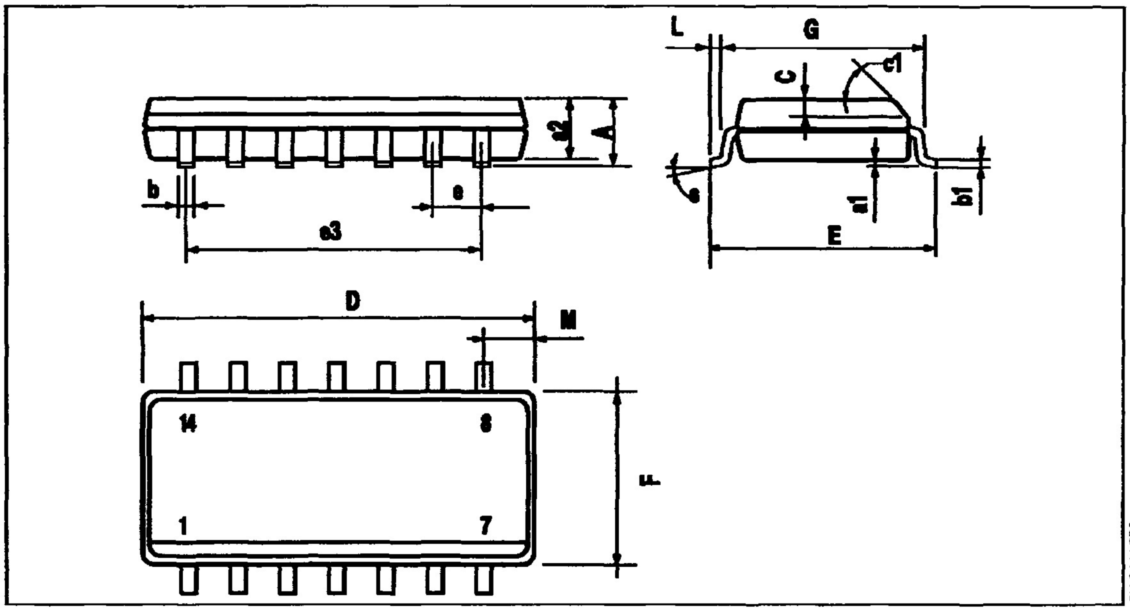
PM-DIP14.EPS

Dimensions	Millimeters			Inches		
	Min.	Typ.	Max.	Min.	Typ.	Max.
a1	0.51			0.020		
B	1.39		1.65	0.055		0.065
b		0.5			0.020	
b1		0.25			0.010	
D			20			0.787
E		8.5			0.335	
e		2.54			0.100	
e3		15.24			0.600	
F			7.1			0.280
i			5.1			0.201
L		3.3			0.130	
Z	1.27		2.54	0.050		0.100

DIP14.TBL

PACKAGE MECHANICAL DATA

14 PINS - PLASTIC MICROPACKAGE (SO)



PM-SO14.EPS

Dimensions	Millimeters			Inches		
	Min.	Typ.	Max.	Min.	Typ.	Max.
A			1.75			0.069
a1	0.1		0.2	0.004		0.008
a2			1.6			0.063
b	0.35		0.46	0.014		0.018
b1	0.19		0.25	0.007		0.010
C		0.5			0.020	
c1	45° (typ.)					
D	8.55		8.75	0.336		0.334
E	5.8		6.2	0.228		0.244
e		1.27			0.050	
e3		7.62			0.300	
F	3.8		4.0	0.150		0.157
G	4.6		5.3	0.181		0.208
L	0.5		1.27	0.020		0.050
M			0.68			0.027
S	8° (max.)					

SO14.TBL