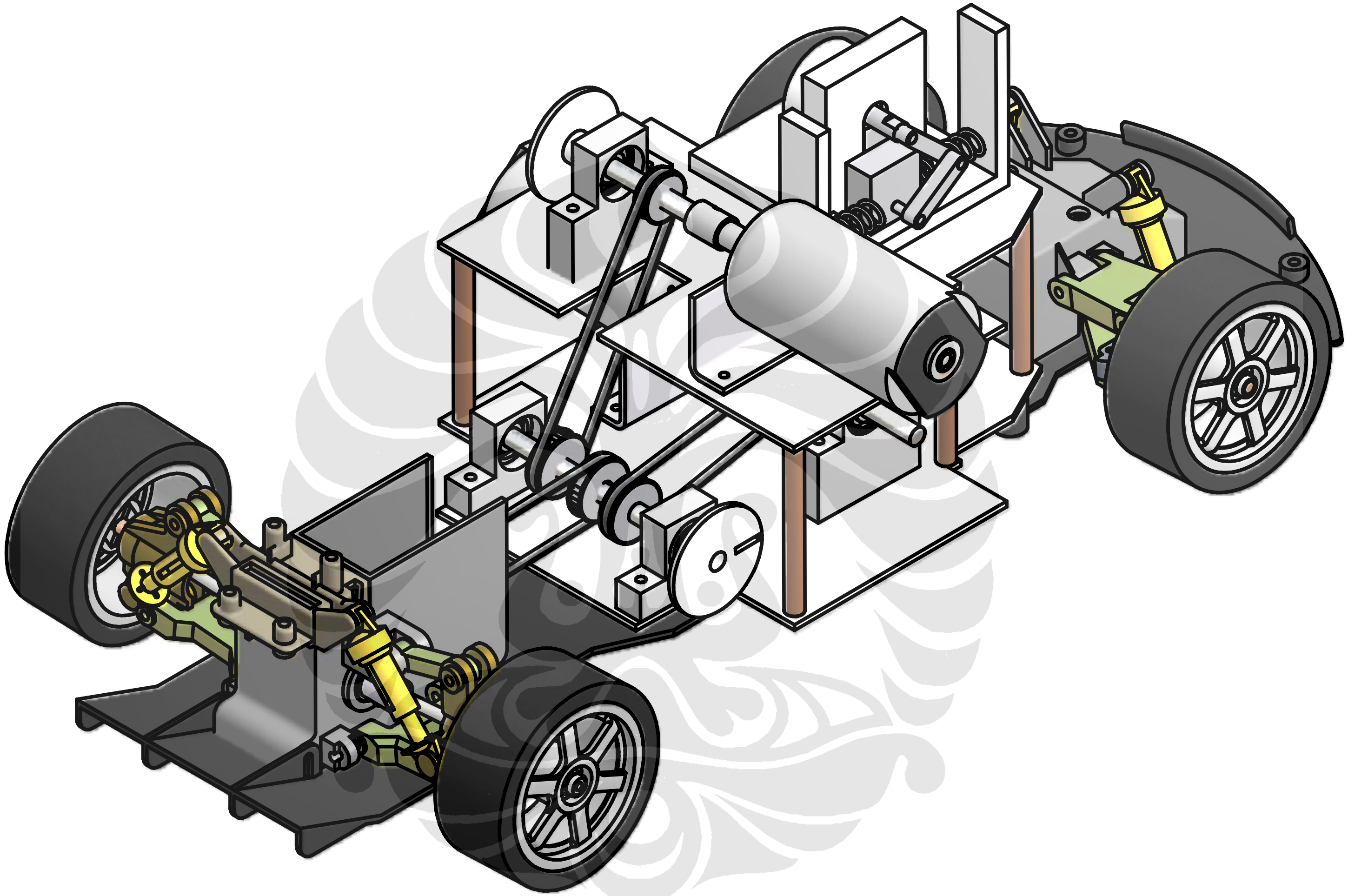
LAMPIRAN



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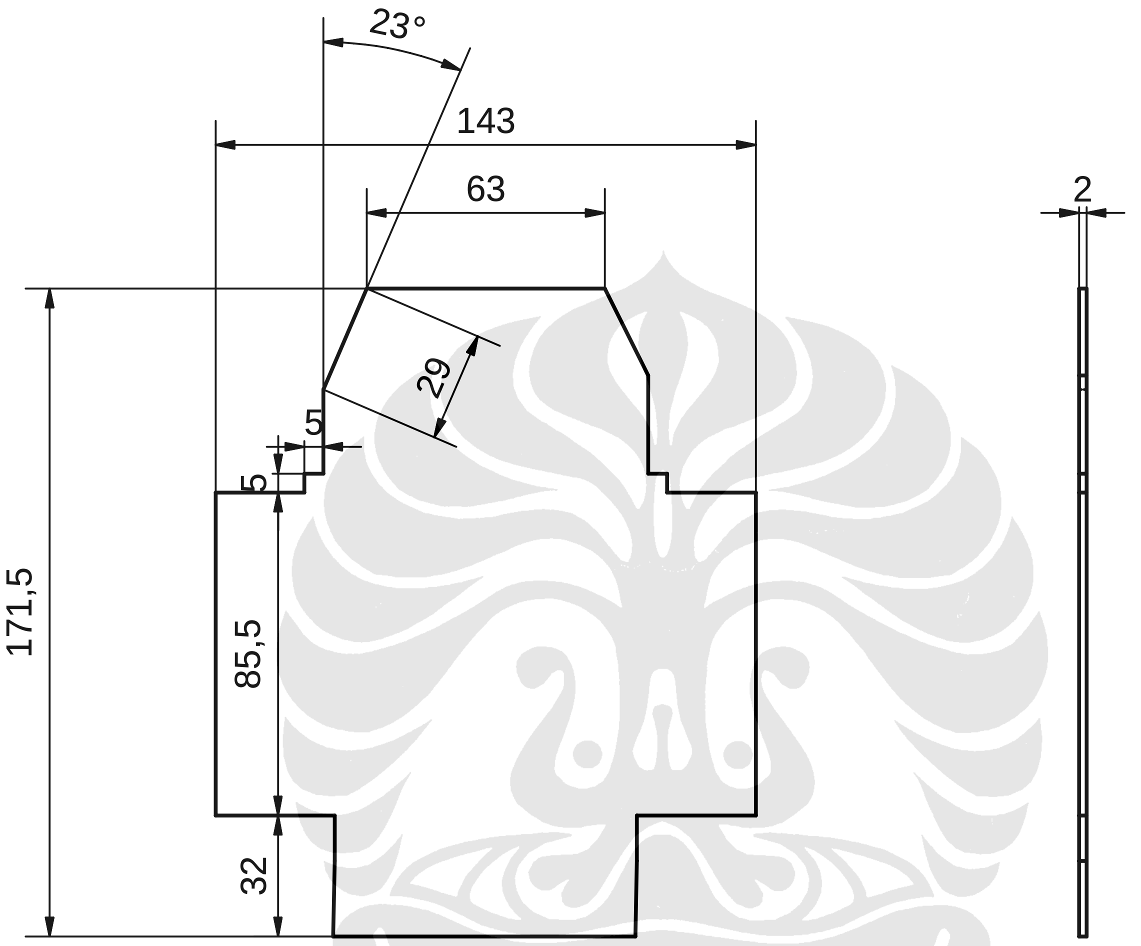
DTM FTUI	SMALL TEST BED		A4



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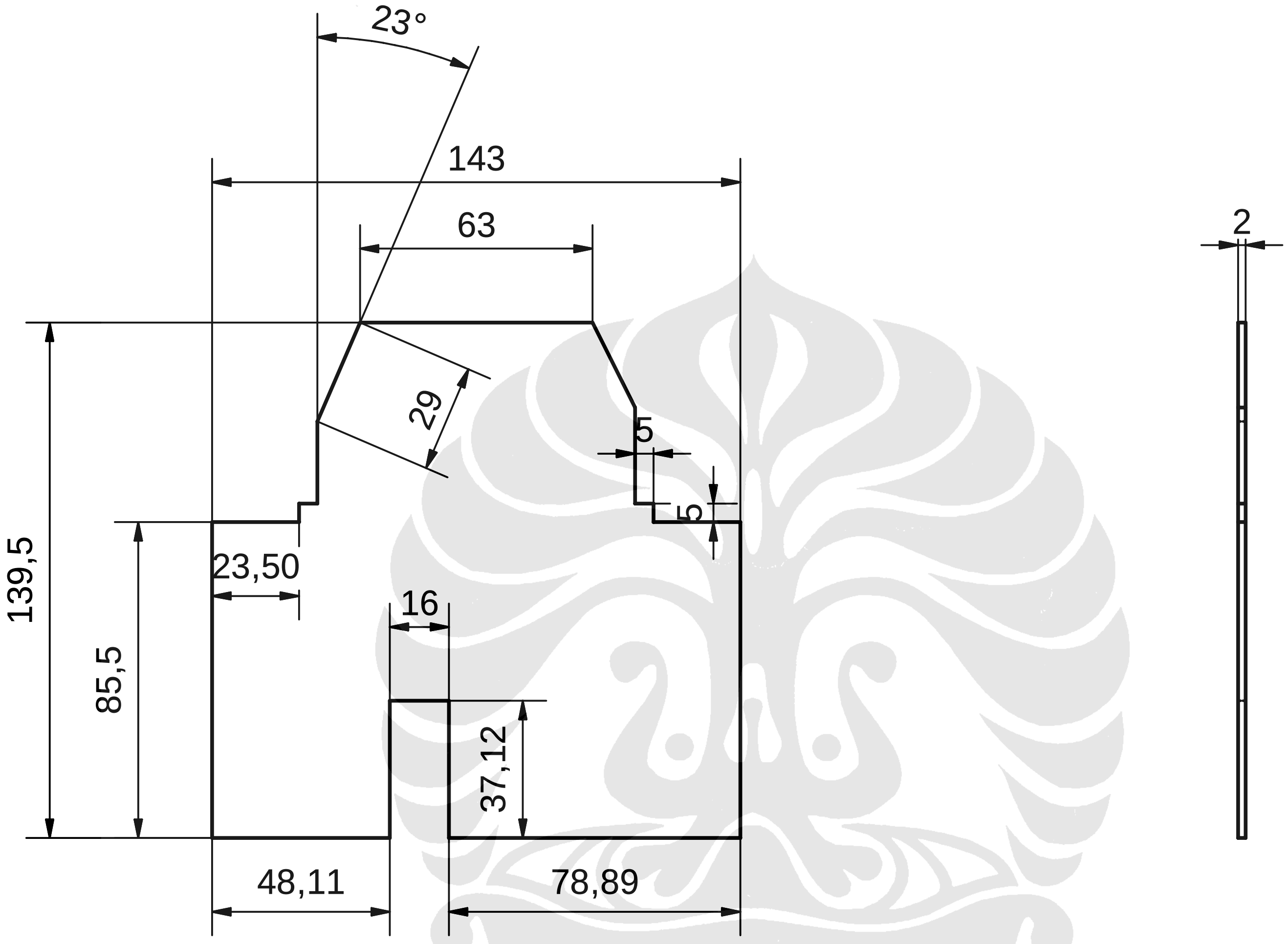
DTM FTUI	CHASIS TENGAH		A4



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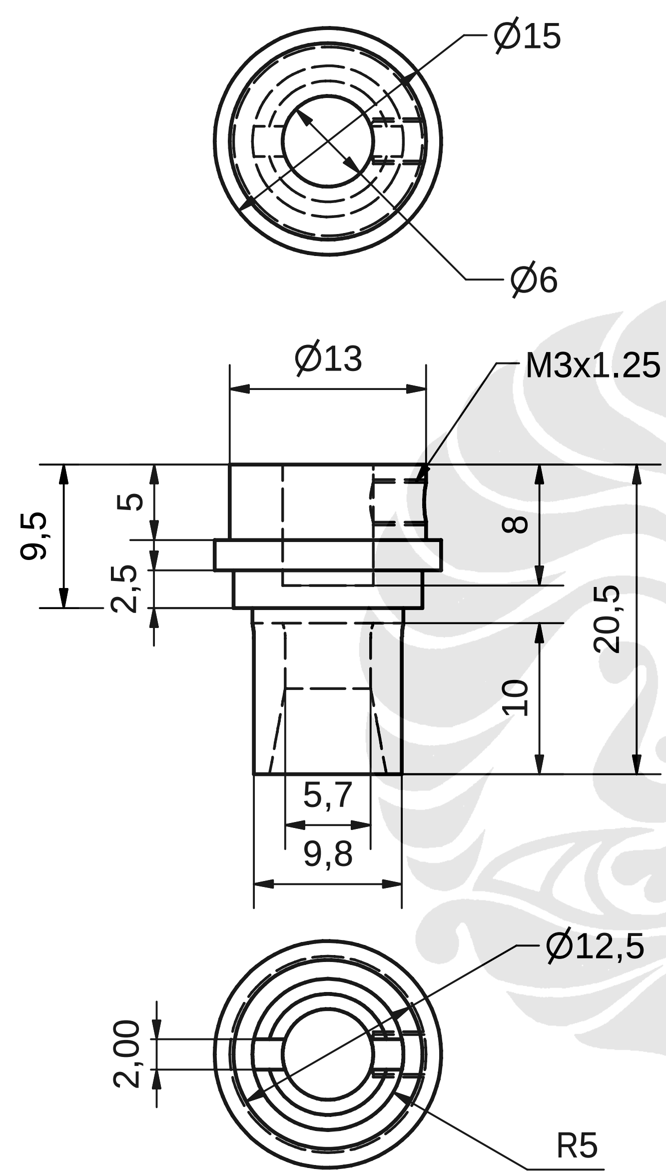
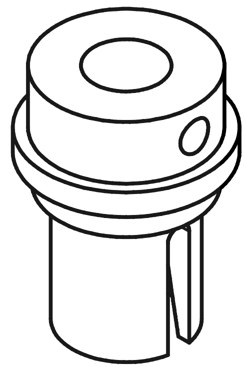
DTM FTUI	CHASIS ATAS		A4





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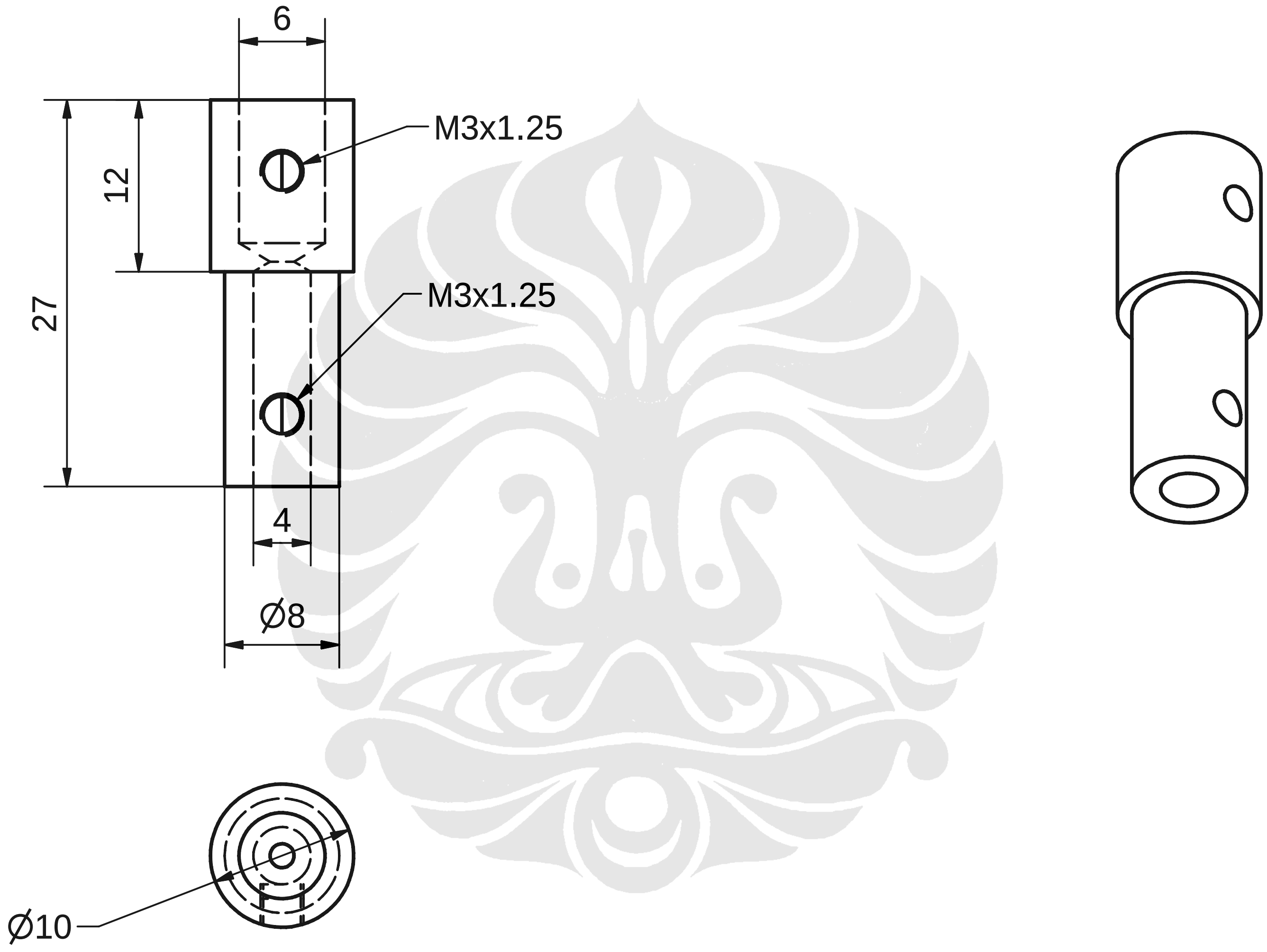
DTM FTUI	HUB BELAKANG		A4



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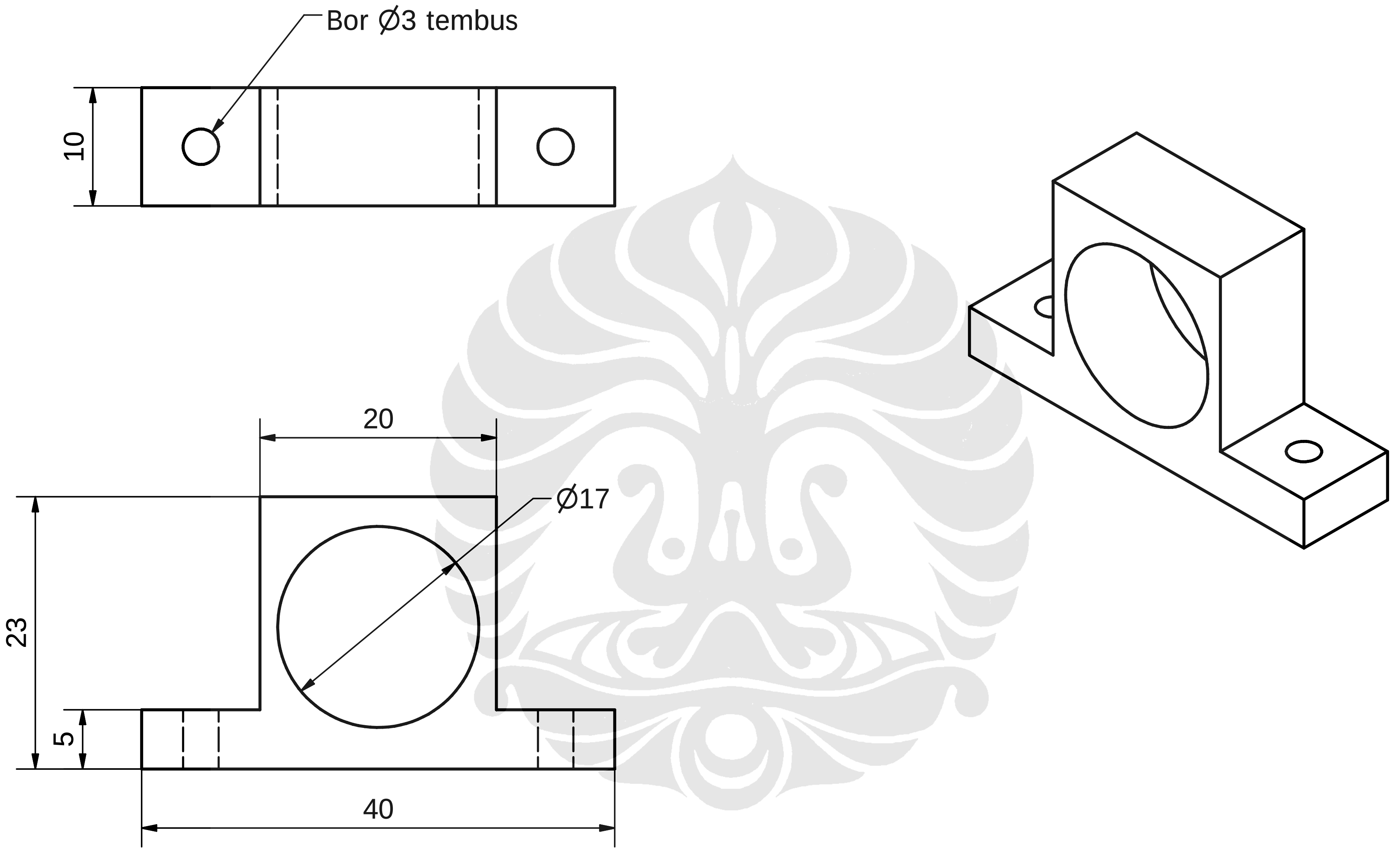
DTM FTUI	HUB		A4



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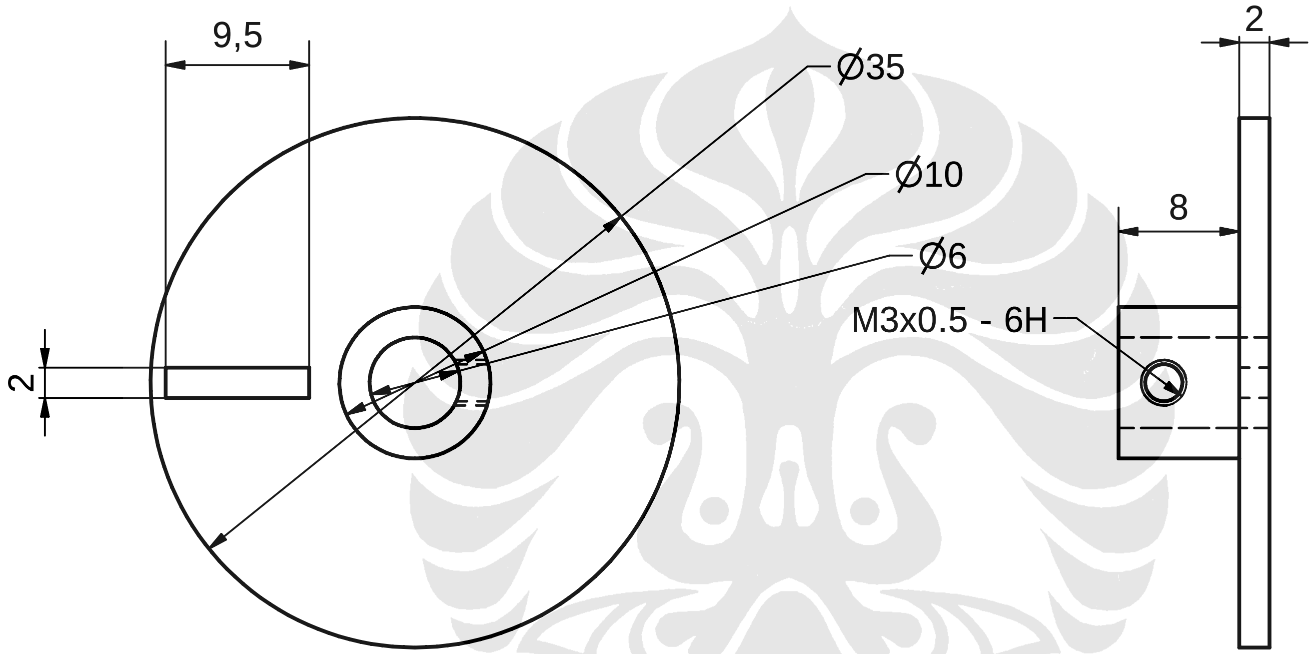
DTM FTUI	RUMAH BEARING		A4



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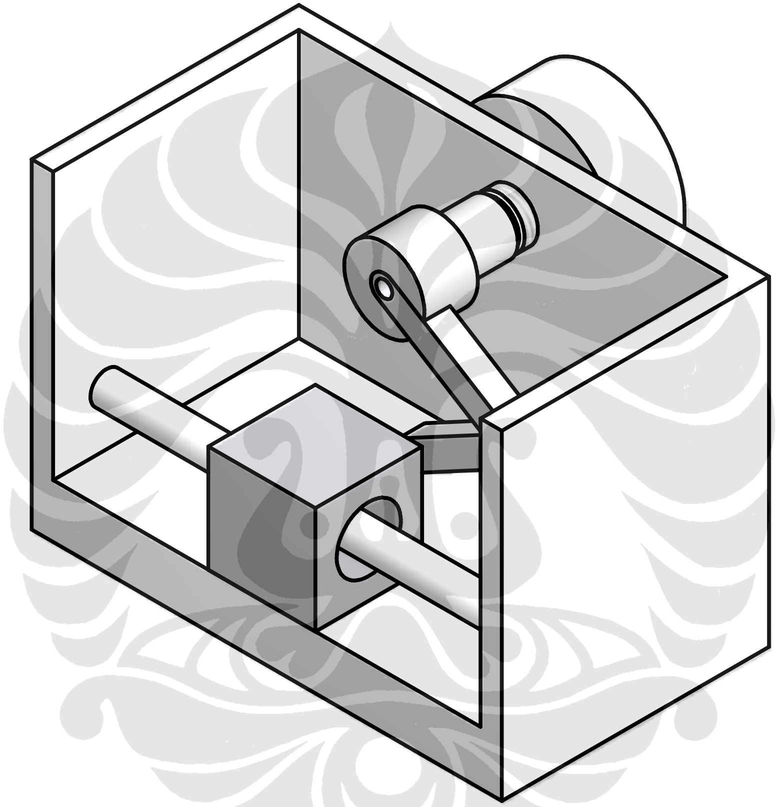
DTM FTUI	PIRINGAN *ENCODER*		A4



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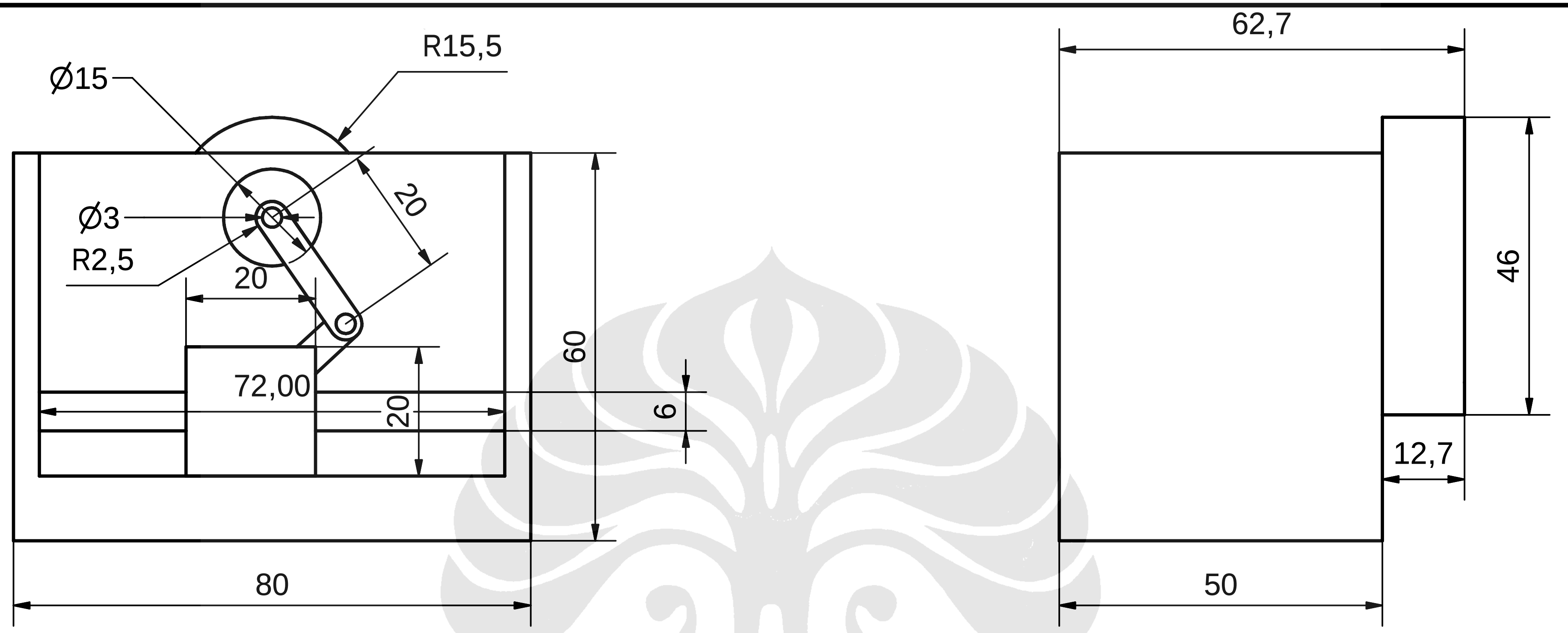
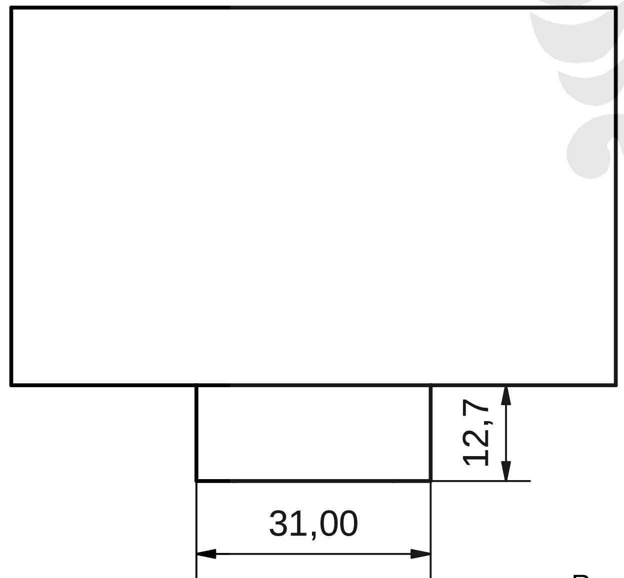
DTM FTUI | SENSOR KEMIRINGAN__2 | A4





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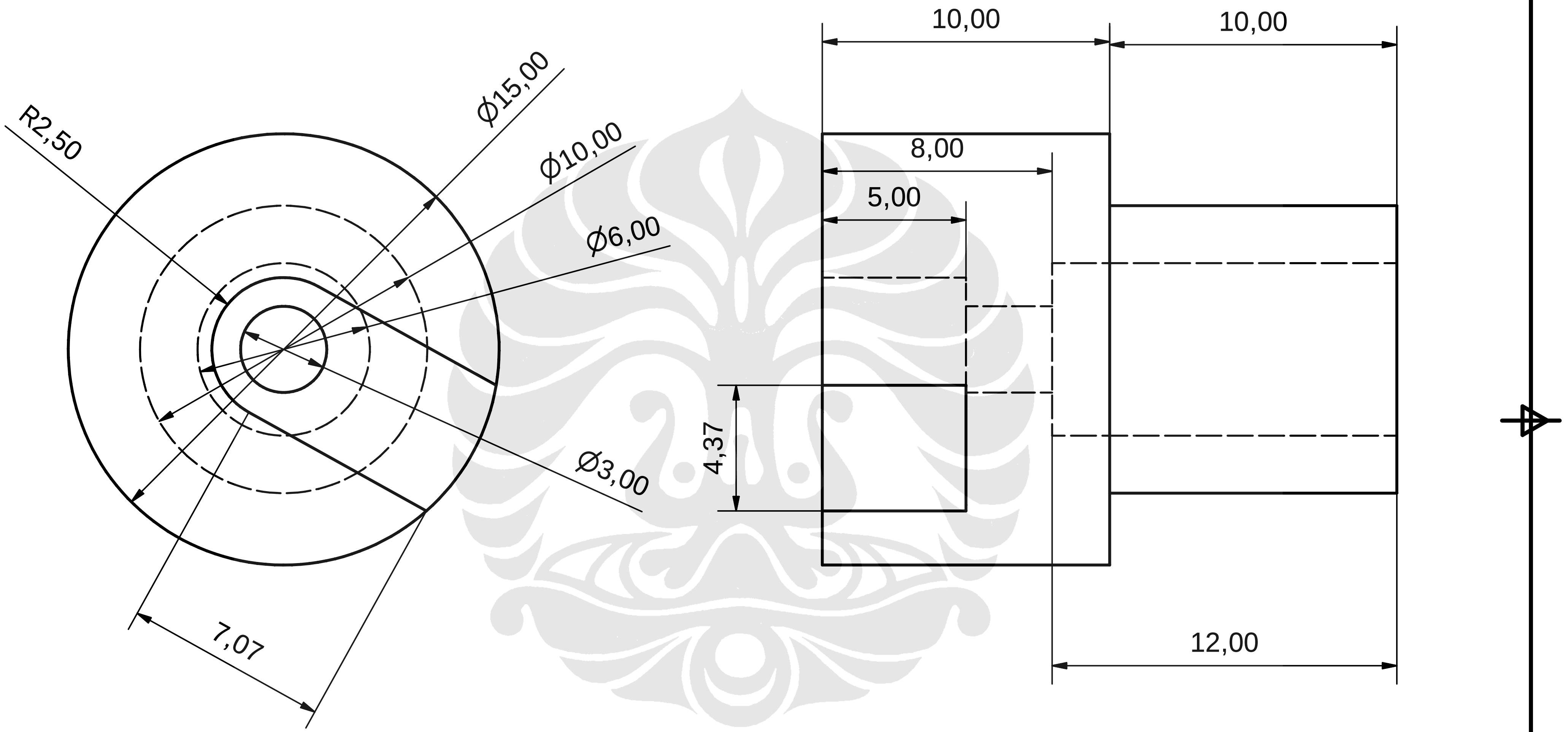
DTM FTUI	SENSOR KEMIRINGAN__2		A4



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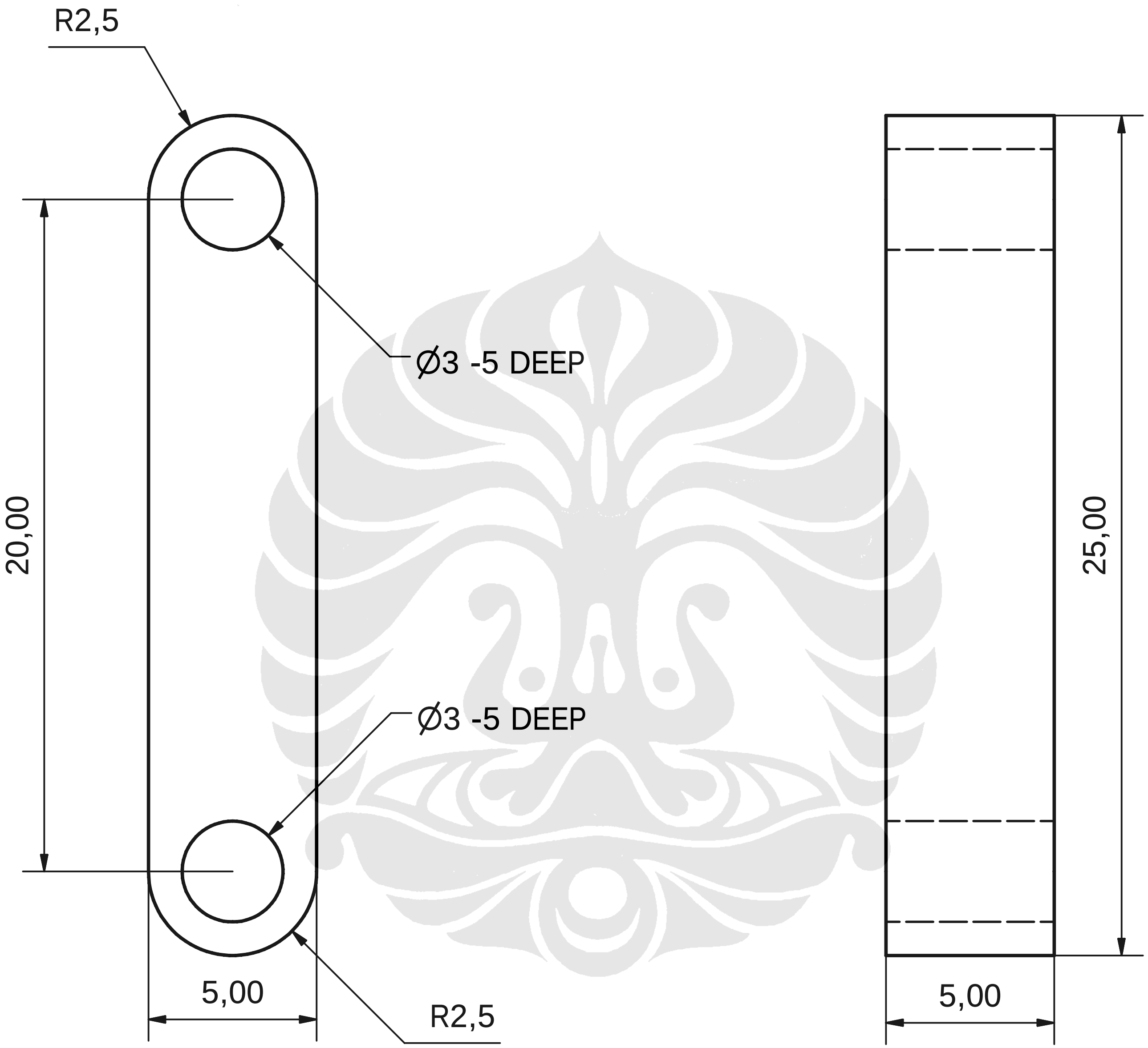
DTM FTUI	HUB LENGAN		A4



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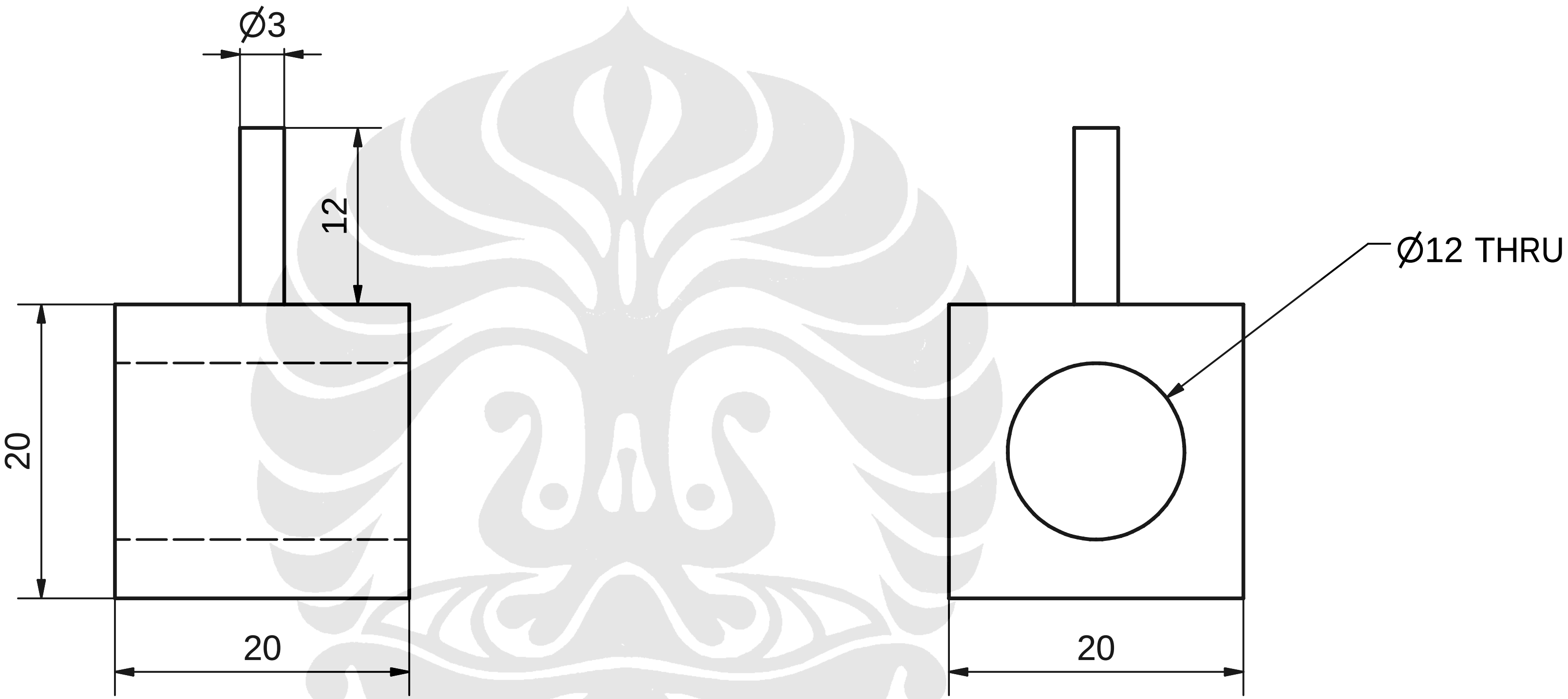
DTM FTUI	BATANG SENSOR		A4



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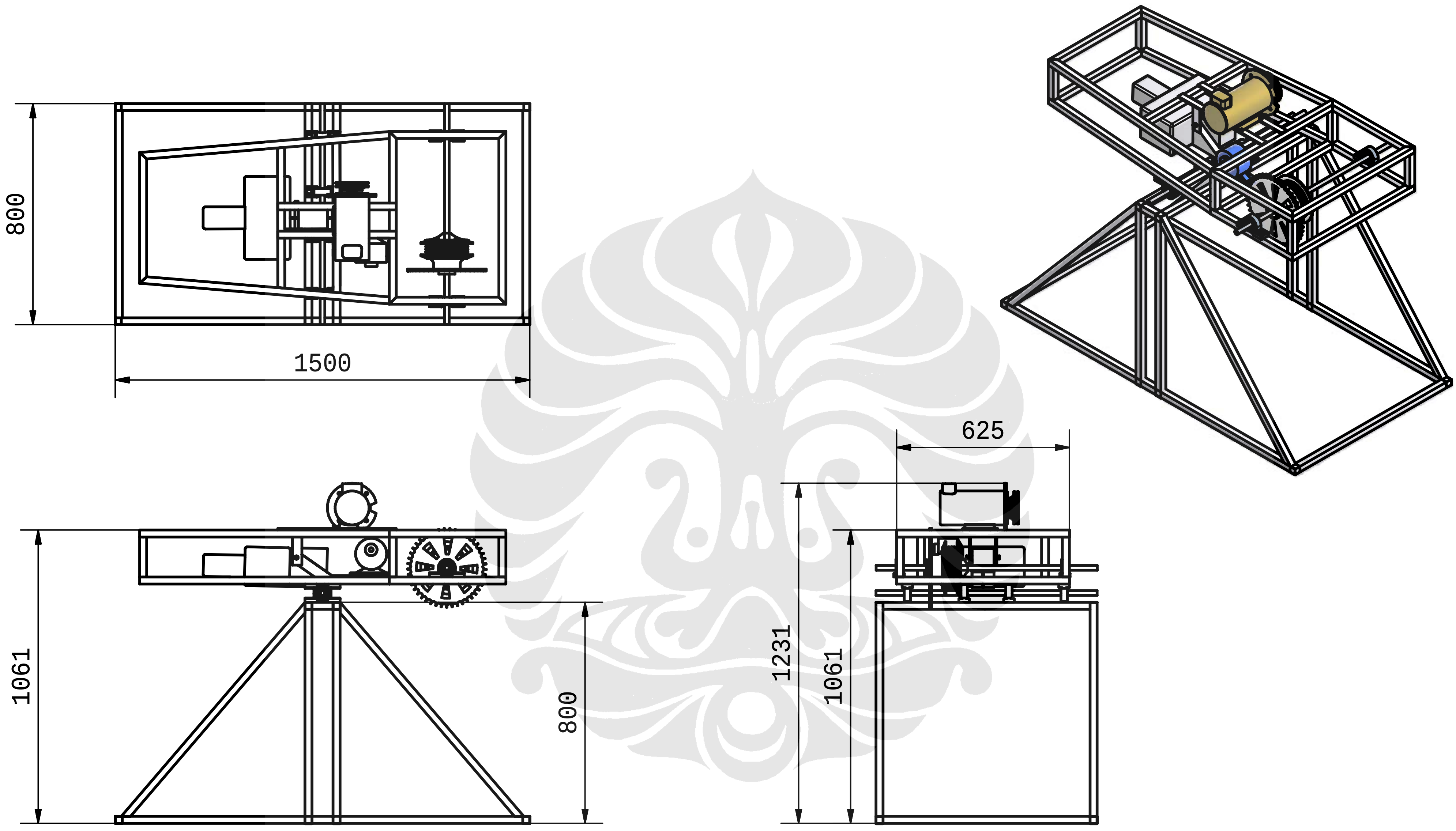
DTM FTUI	MASSA SENSOR		A4



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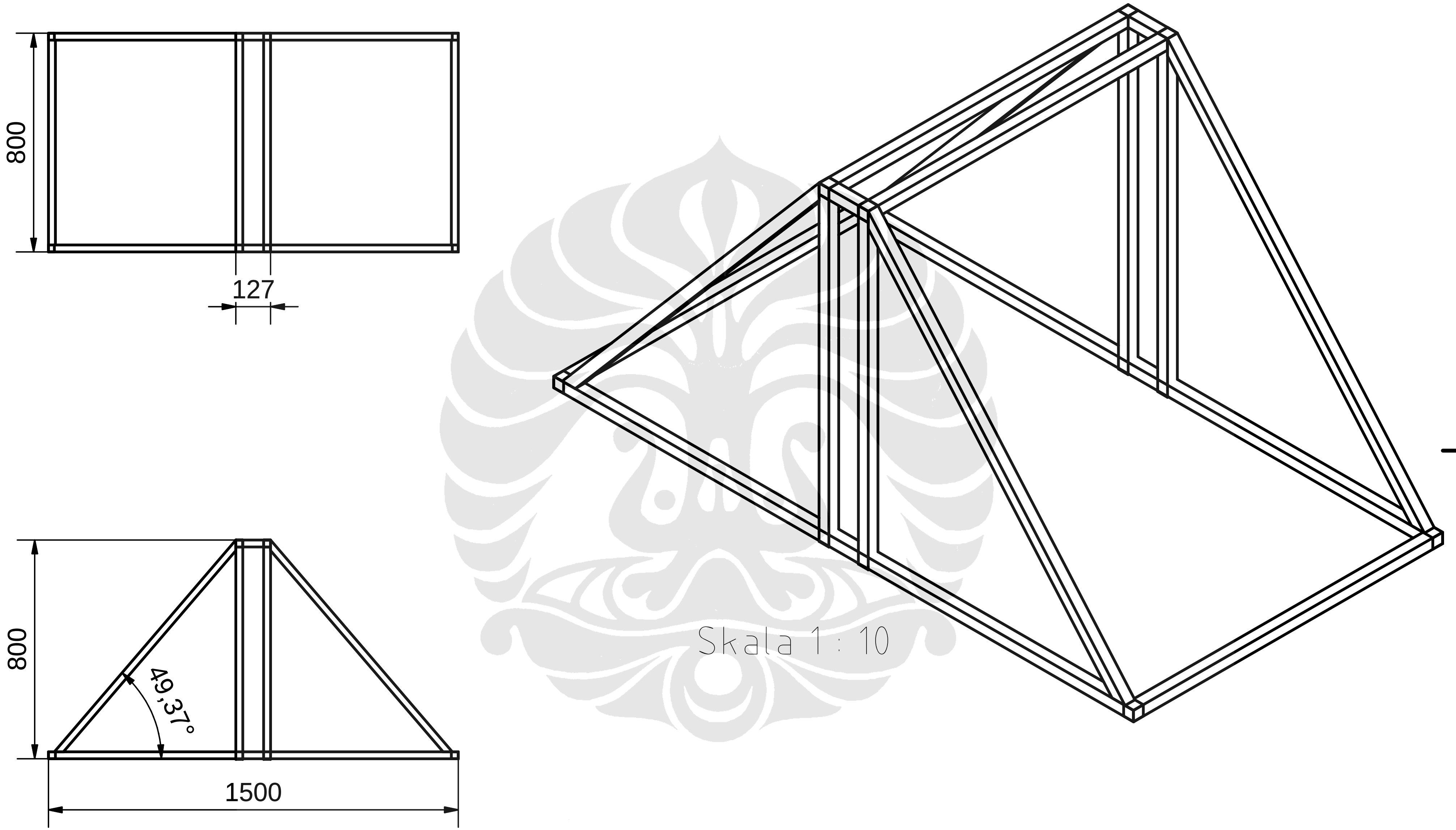
DTM FTUI	LARGE TEST BED		A4



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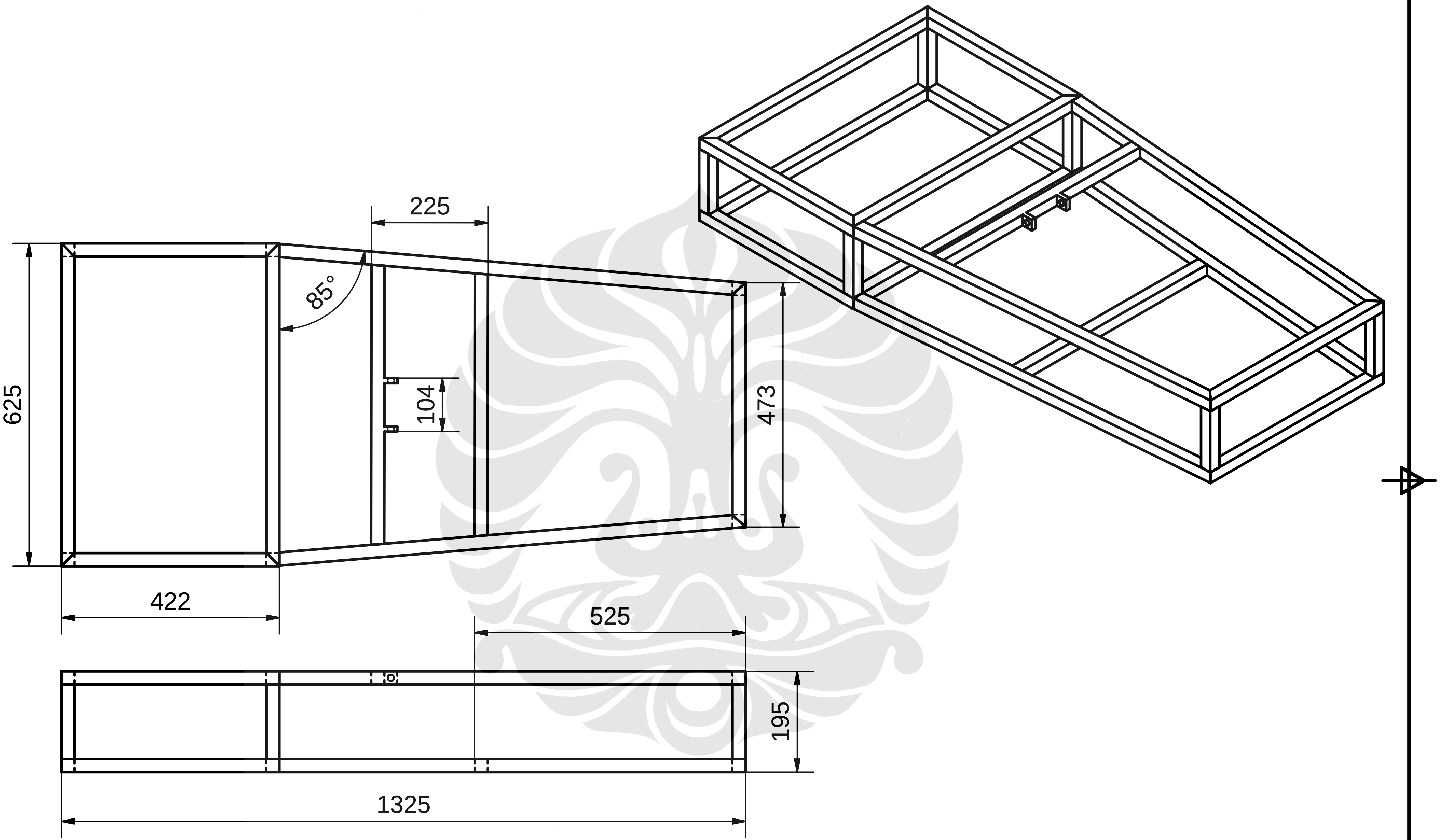
DTM FTUI | LARGE TEST BED_BASE | A4



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tanggal : 01-12-2007
digambar : endiandika t.p./pranadityo
NPM : 0403020289/0403020572
disetujui : DR.Ir.Gandjar Kiswanto
peringatan :

DTM FTUI
LARGE TEST BED_FRAME
A4

S5 Optical Shaft Encoder

Description:

The **S5** series optical shaft encoder is a non-contacting rotary to digital converter. Useful for position feedback or manual interface, the encoder converts real-time shaft angle, speed, and direction into TTL-compatible quadrature outputs with or without index. The encoder utilizes an unbreakable mylar disk, metal shaft and bushing, LED light source, and monolithic electronics. It operates from a single +5VDC supply.

Three shaft torque versions are available. The standard torque version and **M6**-option have a sleeve bushing lubricated with a viscous motion control gel to provide torque and a feel that is ideal for front panel human interface applications.

The **NT**-option (no torque added) has a sleeve bushing and a low viscosity lubricant (that does not intentionally add torque) for low RPM applications where a small amount of torque is acceptable.

The **B**-option and **BM6**-option have a ball bearing rather than a sleeve bushing for high speed, free spinning, and zero torque applications. The ball bearing options are recommended when a pulley, gear, or friction wheel drives the shaft. This eliminates the wear that would otherwise result from the side load even at slow speeds.

A secure connection to the **S5** series encoder is made through a 5-pin (single-ended version) or 10-pin (differential version) finger-latching connector (sold separately). The mating connectors are available from US Digital with several cable options and lengths.

For differential version: the internal differential line driver (26C31) can source and sink 20mA at TTL levels. The recommended receiver is industry standard 26C32. Maximum noise immunity is achieved when the differential receiver is terminated with a 110 ohm resistor in series with a .0047µf capacitor placed across each differential pair. The capacitor simply conserves power; otherwise power consumption would increase by approximately 20mA per pair, or 60mA for 3 pairs.

Features:

- Small size
- Low cost
- Optional Agilent compatible pin-out
- Optional differential / line-driver output
- Positive finger-latching connector
- 2-channel quadrature,TTL squarewave outputs
- 3rd channel index option
- Tracks from 0 to 100,000 cycles/sec
- Ball bearing option tracks to 10,000 RPM
- -40 to +100°C operating temperature
- Single +5VDC supply
- US Digital warrants its products against defects in materials and workmanship for two years. See complete warranty for details.

Differential Electrical Specifications:

Parameter	Min.	Typ.	Max.	Units	Notes
Supply	4.5	5.0	5.5	Volts	
Current Consumption					
Index: 32 CPR	-	28	53	mA	No load
Index: 720, 900, 1000, 1250 CPR	-	56	59	mA	No load
Index: All Other Resolutions	-	58	88	mA	No load
Non-index: <2000 CPR	-	18	43	mA	No load
Non-index: >=2000 CPR	-	58	88	mA	No load
Output Voltage					
Sourcing to +5	2.4	3.4	-	Volts	@ -20mA
Sinking to Ground	-	0.2	0.4	Volts	@ 20mA

- For complete details see the **EM1 / HEDS** data sheet.

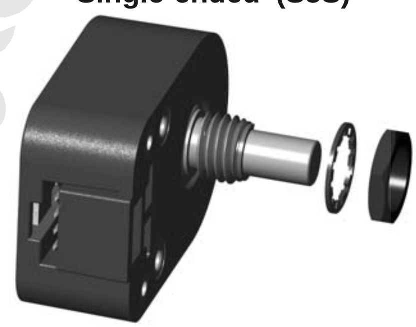
Single-ended Electrical Specifications:

For complete details see the **EM1 / HEDS** data sheet.

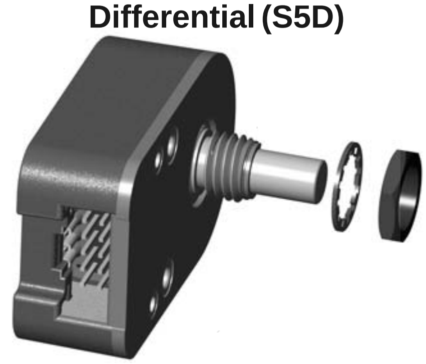
Phase Relationship:

B leads A for clockwise shaft rotation, and A leads B for counterclockwise rotation viewed from the shaft side of the encoder (*see the **EM1 / HEDS** data sheet*).

Single-ended (S5S)



Differential (S5D)



Mounting:

Hole Diameter	.375 in. +.005 - 0
Panel Thickness	.125 in. max.
Panel Nut Max. Torque	20in.-lbs.

Materials:

Shaft	Brass or stainless
Bushing	Brass
Connector	Gold plated

Mechanical Specifications:

Parameter	Sleeve Bushing (Standard or M6-option)	Ball Bearing (B-option or BM6-option)
Acceleration	250,000 rad/sec^2	250,000 rad/sec^2
Vibration	20 g. 5 to 2KHz	20 g. 5 to 2KHz
Shaft Speed	100 RPM max. continuous	10,000 RPM max. continuous
Shaft Rotation	Continuous and reversible	-
Shaft Torque	0.5 ±0.2 in. oz. 0.3 in. oz. max. (**NT**-option)	0.05 in. oz. max.
Shaft Loading	2 lbs. max. dynamic 20 lbs. max. static	1 lb. max.
Bearing Life	-	$(40/P)^3$ = life in millions of revs. where P = radial load in pounds
Weight		
Single-ended (**S5S**)	1.01 oz.	1.15 oz.
Differential (**S5D**)	1.28 oz.	1.42 oz.
Shaft Runout	0.0015 T.I.R. max.	0.0015 T.I.R. max.

US DIGITAL
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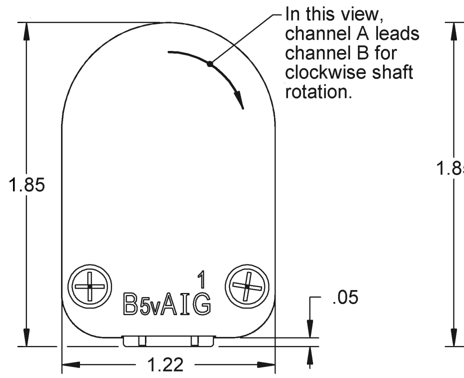
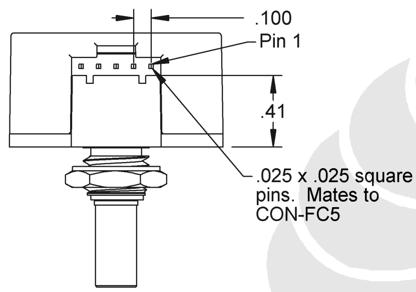
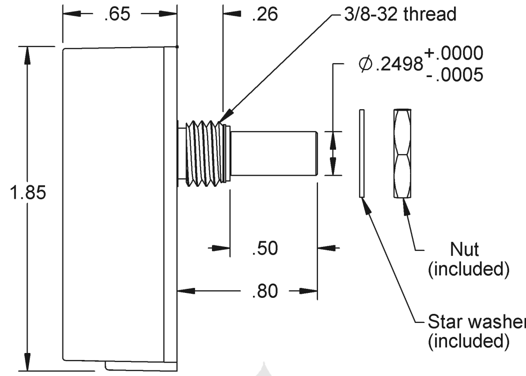
Local: 360.260.2468 ▪ Sales: 800.736.0194
Support: 360.397.9999 ▪ Fax: 360.260.2469
1400 NE 136th Ave. ▪ Vancouver, Washington ▪ 98684 ▪ USA

Single-ended Mechanical Drawings (S5S):

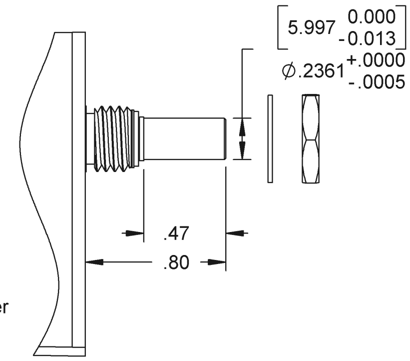




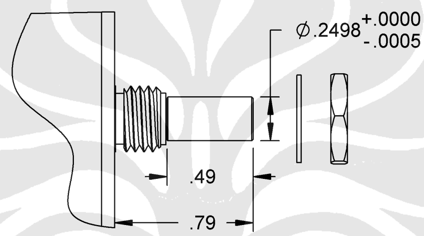
1/4" Sleeve Bushing (Default)



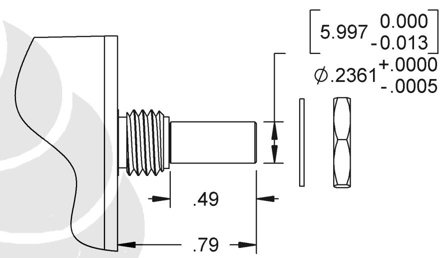
6mm Sleeve Bushing (M6-option)



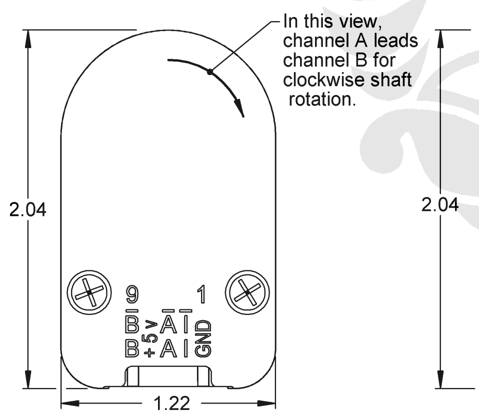
1/4" Ball Bearing (B-option)

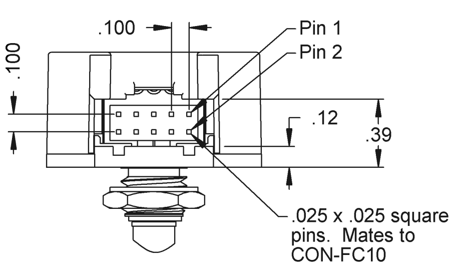


6mm Ball Bearing (BM6-option)

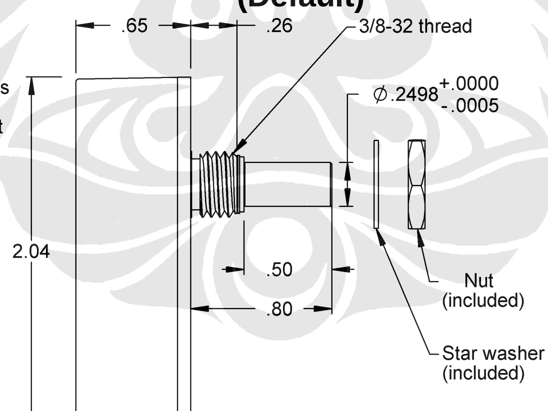


Differential Mechanical Drawings (S5D):

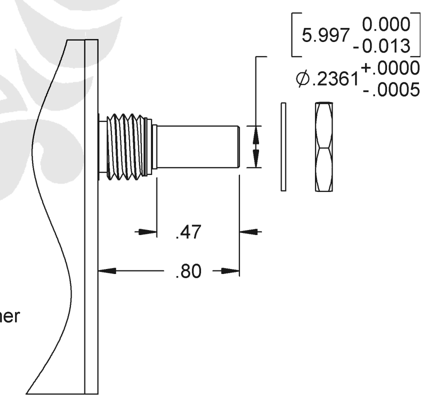




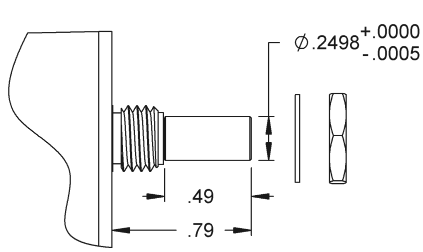
1/4" Sleeve Bushing (Default)



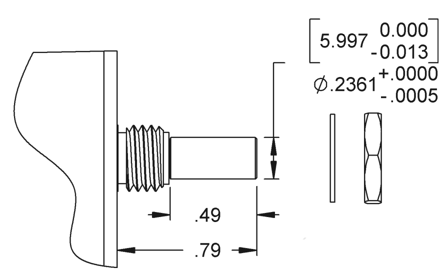
6mm Sleeve Bushing (M6-option)



1/4" Ball Bearing (B-option)



6mm Ball Bearing (BM6-option)



Compatible Cables / Connectors:

Finger-latching:

5-pin	10-pin	Description
CON-FC5-22*	CON-FC10	Connector
CA-3133-1FT**	-	Connector on one end with 4 12" wires
CA-3132-1FT**	-	Connector on one end with 5 12" wires
CA-3131-6FT**	CA-4217-6FT	Connector on one end of a 6' shielded round cable
-	CA-4174-6FT***	Same as CA-4217, but for L-option only
CA-3620-6FT**	CA-3619-6FT	Connectors on both ends of a 6' shielded round cable
-	CA-3807-FT***	Same as CA-3807, but for L-option only

* 22 AWG is standard. 24, 26 and 28 AWG are also available.
** Single-ended output and accompanying cables are typically designed for cable lengths of 6 feet or less; for longer cable lengths, differential output and accompanying cables are recommended.
*** Avago / Agilent / HP compatible cable assembly.

Attention:
- Specify cable length when ordering.
- Custom cable lengths are available. See the **Cables / Connectors** data sheet for more information.

Pin-outs:

Pin	5-pin Single-ended	10-pin Differential Standard	10-pin Differential Avago (L-option)
1	Ground	Ground	No connection
2	Index	Ground	+5VDC power
3	A channel	Index-	Ground
4	+5VDC power	Index+	No connection
5	B channel	A- channel	A- channel
6		A+ channel	A+ channel
7		+5VDC power	B- channel
8		+5VDC power	B+ channel
9		B- channel	Index-
10		B+ channel	Index+

Ordering Information:

S5S Standard:	S5S Index/HiRes: (Hi Res: >=1000 CPR)	S5D Standard:	S5D Index/HiRes: (Hi Res: >=1000 CPR)
$52.00 / 1	$61.36 / 1	$65.10 / 1	$74.87 / 1
$47.25 / 10	$55.76 / 10	$60.90 / 10	$70.04 / 10
$43.05 / 50	$50.80 / 50	$56.70 / 50	$65.21 / 50
$40.95 / 100	$48.32 / 100	$53.55 / 100	$61.58 / 100

Cost Modifiers:
- Add $8 for **B**-option.
- Add $5 for **M6**-option.
- Add $13 for **BM6**-option.

S5 [ ] — [ ] — [ ]

Version:
S = Single-ended.
D = Differential.

CPR:

32**	360
50	400
96	500
100	540*
110*	720**
120*	900**
192	1000
200	1016*
250	1024
256	1250**

Options: (specify in order shown)
Blank (default) = 1/4" dia. sleeve bushing (standard torque).
I = Index (3rd channel).
L = Avago / Agilent / HP compatible pin-out.***
B = 1/4" dia. ball bearing (free spinning).****
M6 = 6mm dia. sleeve bushing (standard torque).
BM6 = 6mm dia. ball bearing (free spinning).****
NT = Replaces standard torque with no torque added.

Notes:
***** Index option not available.
** 32, 720, 900, 1000, 1250 CPR only available with index.
*** Only available with differential version (**S5D**).
**** Not available with **NT**-option (no torque added).

Technical Data, Rev. 06.11.07, June 2007

EM1 / HEDS **Transmissive Optical Encoder Module**

Start Here:

- Use charts below to determine which module family your application uses (based on CPR/CPI).

1" Resolutions:

CPR	Non-Index	With Index
32	n/a	EM1
50	HEDS	HEDS
96	HEDS	HEDS
100	HEDS	HEDS
110	HEDS	n/a
120	HEDS	n/a
192	HEDS	HEDS
200	HEDS	HEDS
250	HEDS	HEDS
256	HEDS	HEDS
360	HEDS	HEDS
400	HEDS	HEDS
500	HEDS	HEDS
512	HEDS	HEDS
540	HEDS	n/a
720	n/a	EM1
900	n/a	EM1
1000	HEDS	EM1
1016	HEDS	n/a
1024	HEDS	EM1
1250	n/a	EM1

2" Resolutions:

CPR	Non-Index	With Index
64	n/a	EM1
100	HEDS	HEDS
200	HEDS	HEDS
400	HEDS	HEDS
500	HEDS	HEDS
512	HEDS	n/a
1000	HEDS	HEDS
1024	HEDS	HEDS
1800	n/a	EM1
2000	HEDS	HEDS
2048	HEDS	HEDS
2500	EM1	EM1

Linear Strip Resolutions:

CPI	Non-Index	With Index
120	n/a	EM1
125	n/a	EM1
127	n/a	EM1
150	n/a	EM1
180	HEDS	n/a
200	n/a	EM1
250	n/a	EM1
300	HEDS	n/a
360	HEDS	n/a
500	n/a	EM1

Features:

- Two channel quadrature output with index pulse
- No signal adjustment
- TTL Compatible
- Single +5V supply
- The **EM1** and **HEDS** are both RoHS compliant
- US Digital warrants its products against defects and workmanship for two years. See complete warranty for details.

EM1:

- Resolutions up to 2500 CPR (10,000 PPR)
- Internal 0.1 ufd bypass capacitor
- -55°C to 125°C operating temperature

HEDS:

- Resolutions up to 2048 CPR (8192 PPR)
- -40°C to 100°C operating temperature

Description:

The **EM1** and **HEDS** products are transmissive optical encoder modules. These modules are designed to detect rotary or linear position when used together with a codewheel or linear strip. The **EM1** and **HEDS** modules consist of a lensed LED source and a monolithic detector IC enclosed in a small polymer package. These modules use phased array detector technology to provide superior performance and greater tolerances over traditional aperture mask type encoders.

Both the **EM1** and **HEDS** module provide digital quadrature outputs. The **EM1** comes standard with a third index channel output on all resolutions. The **HEDS** is available with a third index channel output on only some resolutions.

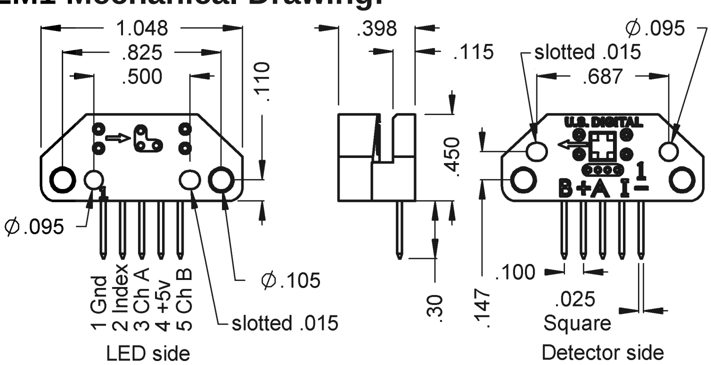
The **EM1** and **HEDS** transmissive optical encoder modules are powered from a single +5VDC power supply. Additional power supply voltages for the **EM1** will be available in the near future. The **EM1** single-ended outputs are capable of sinking or sourcing 8mA each.

The resolution of the modules and encoder disks or linear strips must match. Two mounting holes are provided to accept screws up to .105" dia. Both the **EM1** and **HEDS** have identical mounting and pin-out configurations.

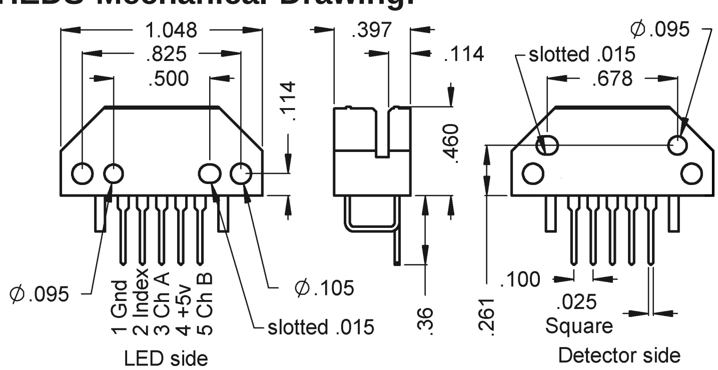
For open collector and higher voltage applications, add the **PC3** device (*see the **PC3** data sheet*), or for differential cable driver outputs, add the **PC4** device (*see the **PC4** data sheet*). Encoder disks, linear strips, quadrature decoder chips, counter chips, computer interface boards, mating connectors and cables are also available.

The **EM1** and **HEDS** are both RoHS compliant.

EM1 Mechanical Drawing:

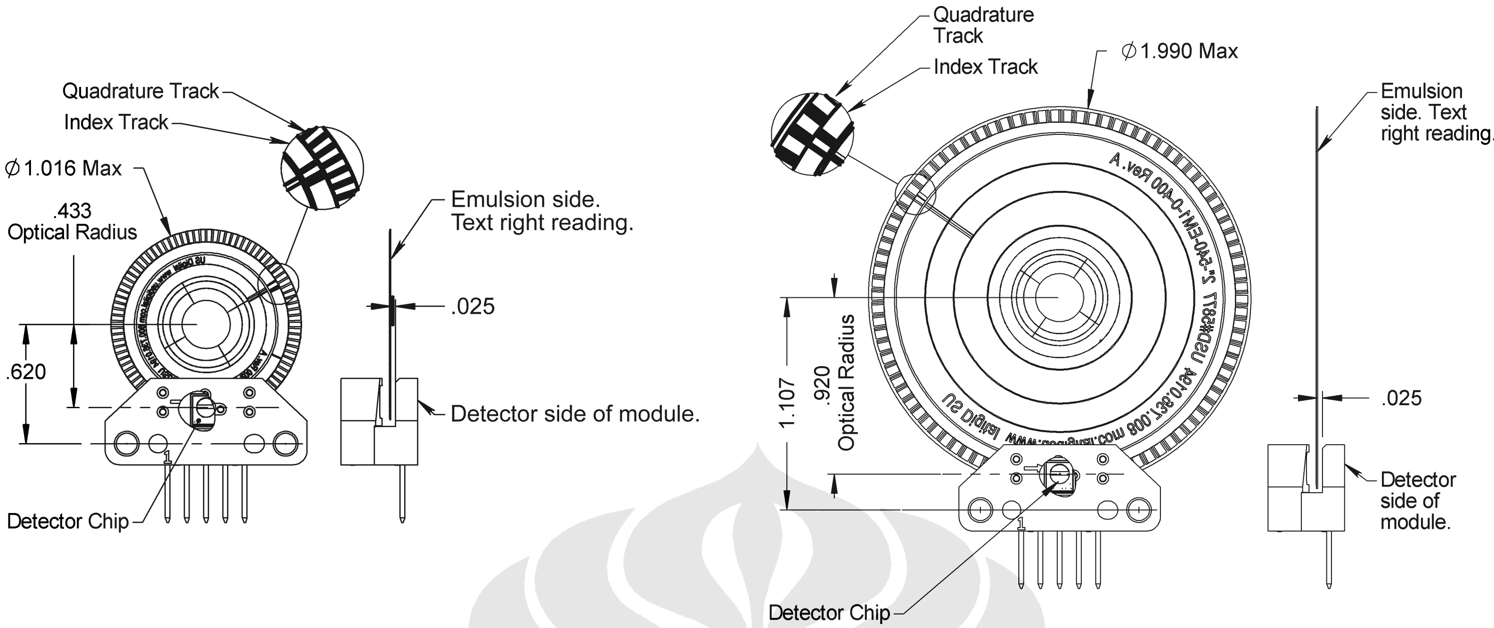


HEDS Mechanical Drawing:

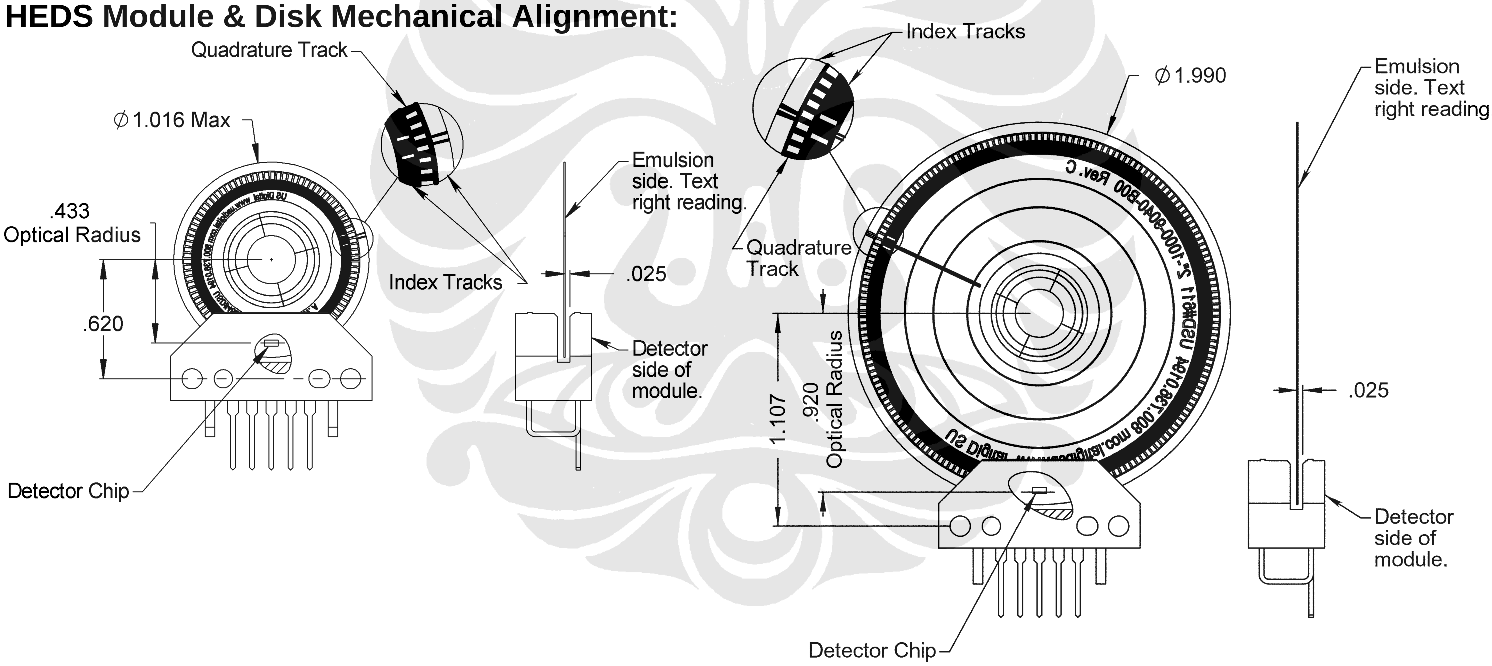


EM1 / HEDS Transmissive Optical Encoder Module

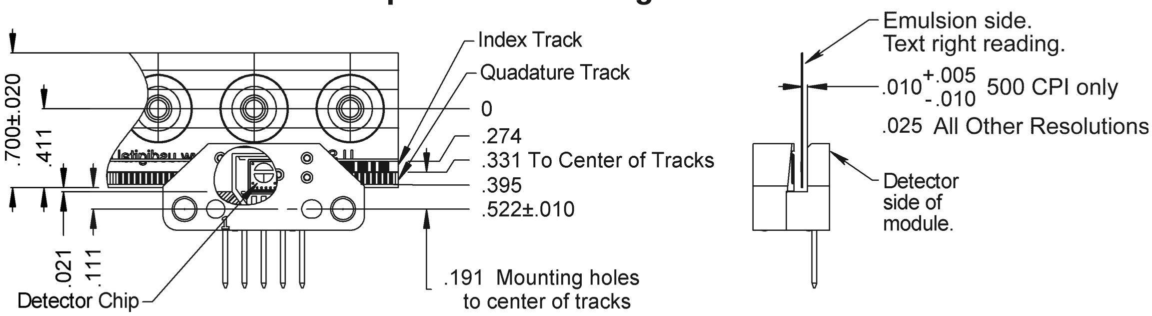
EM1 Module & Disk Mechanical Alignment:



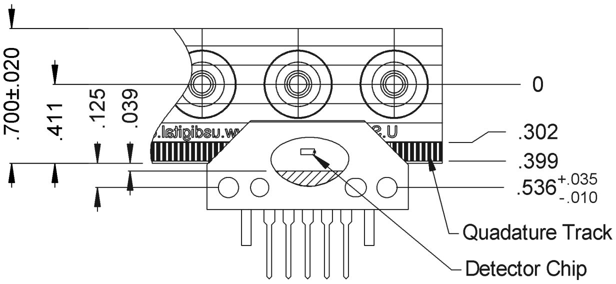
HEDS Module & Disk Mechanical Alignment:

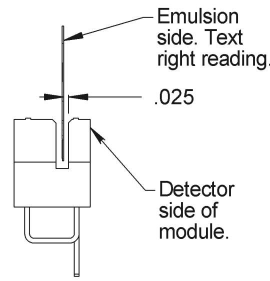


EM1 Module & Linear Strip Mechanical Alignment:



HEDS Module & Linear Strip Mechanical Alignment:





Encoding Characteristics:

- Specifications apply over entire operating temperature range. Values are for the worst error over a full rotation.
- Refer to Timing Diagram on next page.

Parameter	Symbol	Min.	Typ.	Max.	Units
Cycle Error					
HEDS (2000 or 2048 CPR only)		-	3.0	7.5	°e
EM1 & HEDS (All Other Resolutions)		-	3.0	5.5	°e
Symmetry					
HEDS (2000 or 2048 CPR only)		130	180	230	°e
EM1 & HEDS (All Other Resolutions)		150	180	210	°e
Quadrature					
HEDS (2000 or 2048 CPR only)		40	90	140	°e
EM1 & HEDS (All Other Resolutions)		60	90	120	°e
Index Pulse Width					
HEDS (2000 or 2048 CPR only)	Po	40	90	140	°e
EM1 & HEDS (All Other Resolutions)	Po	60	90	120	°e
Ch. I Rise After Ch. B or Ch. A Fall					
EM1	t1	10	100	250	ns
HEDS (2000 or 2048 CPR only)	t1	10	450	1500	ns
HEDS (All Other Resolutions)	t1	-300	100	250	ns
Ch. I Fall After Ch. A or Ch. B Rise					
EM1	t2	70	150	300	ns
HEDS (2000 or 2048 CPR only)	t2	10	250	1500	ns
HEDS (All Other Resolutions)	t2	70	150	1000	ns

Recommended Operating Conditions:

Parameter	Min.	Max.	Units	Notes
Temperature				
EM1	-55	125	°C	
HEDS	-40	100	°C	
Supply Voltage	4.5	5.5	Volts	Ripple <100mV$_{P-P}$
Load Capacitance	-	100	pF	
Count Frequency	-	100	kHz	rpm/60 x cycles/rev.

Electrical Specifications:

- Specifications apply over entire operating temperature range. Typical values are specified at Vcc = 5.0V and 25°C.
- Refer to Timing Diagram on next page.

Parameter	Min.	Typ.	Max.	Units	Notes
Output Voltage	-0.5	-	Vcc	Volts	
Supply Current					
EM1 (32 thru 250 CPR)	-	27	30	mA	
EM1 (All Other Resolutions)	-	55	57	mA	
HEDS (Index or 1" >=1000 CPR or 2" >=2000 CPR only)	30	57	85	mA	
HEDS (Non-index or All Other Resolutions)	-	17	40	mA	
Output Low*					
EM1	-	-	0.5	Volts	I_{OL} = 8.0mA max.
HEDS (Index or 1" >=1000 CPR or 2" >=2000 CPR only)	-	-	0.4	Volts	I_{OL} = 3.86mA max.
HEDS (Non-index or All Other Resolutions)	-	-	0.4	Volts	I_{OL} = 3.2mA max.
Output High*					
EM1	2.0	-	-	Volts	I_{OH} = -8.0mA max.
HEDS (Index or 1" >=1000 CPR or 2" >=2000 CPR only)	2.4	-	-	Volts	I_{OH} = -200µA max.
HEDS (Non-index or All Other Resolutions)	2.4	-	-	Volts	I_{OH} = -40µA max.
Output Current Per Channel					
EM1	-8.0	-	8.0	mA	
HEDS	-1.0	-	5.0	mA	

* Unloaded high level output voltage is 4.80V typically, 4.2V minimum.

Phase Relationship:

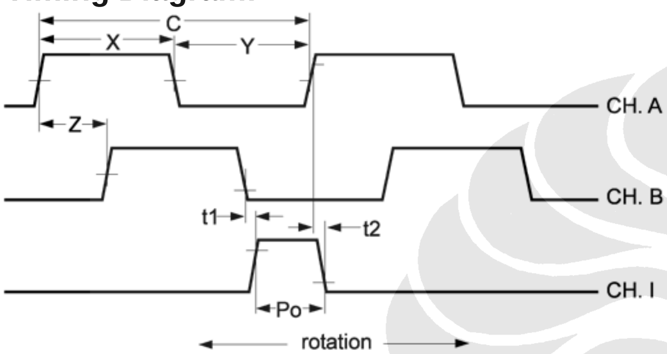
For Shaft Encoders: (View the encoder so the shaft / bushing side is facing up.)
- A leads B in a clockwise rotation; B leads A in a counterclockwise rotation for the following products: **H1.**
- B leads A in a clockwise rotation; A leads B in a counterclockwse rotation for the following products: **H15, H3**, **H5, H6, HB5M, HB6M, HD25**, **S1**, **S2**, **S5**, **S6** and **SP-16.**

For Kit Encoders: (View the encoder so the cover side is facing up.)
- A leads B in a clockwise rotation; B leads A in a counterclockwise rotation for the following products: **E3**, **E5** and **E6.**
- B leads A in a clockwise rotation; A leads B in a counterclockwise rotation for the following products: **E2.**

For Probe Encoders:
- A leads B in inward plunger motion; B leads A in outward plunger motion for the following products: **PE.**

For Inclinometers: (View the inclinometer so the cover side is facing up.)
- A leads B in a clockwise rotation; B leads A in a counterclockwise rotation for the following products: **T5** and **T6.**

Timing Diagram:



CPR (N): The number of Cycles Per Revolution.
One Shaft Rotation: 360 mechanical degrees, N cycles.
One Electrical Degree (°e): 1/360th of one cycle.
One Cycle (C): 360 electrical degrees (°e). Each cycle can be decoded into 1 or 4 codes, referred to as X1 or X4 resolution multiplication.
Symmetry: A measure of the relationship between (X) and (Y) in electrical degrees, nominally 180°e.
Quadrature (Z): The phase lag or lead between channels A and B in electrical degrees, nominally 90°e.
Index (CH I.): The index output goes high once per revolution, coincident with the low states of channels A and B, nominally 1/4 of one cycle (90°e).
Position Error: The difference between the actual shaft position and the position indicated by the encoder cycle count.
Cycle Error: An indication of cycle uniformity. The difference between an observed shaft angle which gives rise to one electrical cycle, and the nominal angular increment of 1/N of a revolution.

EM1 / HEDS Encoder Module Differences:

US Digital is the designer and manufacturer of the **EM1** transmissive optical encoder module. The design of the **EM1** provides electrical and mechanical compatibility with the Agilent **HEDS-9000**, **HEDS-9100**, **HEDS-9200**, **HEDS-9040**, and **HEDS-9140** series modules. Non-index codewheels are interchangable between the **EM1** and **HEDS** modules. The process of switching from the **HEDS** to the **EM1** module should not require any mechanical or electrical changes. Simply use the **EM1** and matching codewheel in place of the **HEDS** module and codewheel.

The **EM1** has a built in index channel and is available on all resolutions, for both rotary disks and linear strips. The **EM1** offers improved output drive capability and will source and sink 8mA at TTL levels. The current consumption is reduced over Agilent index versions (27mA vs. 57mA typical). Physically the **EM1** has no external wire loops which interfere when mounting. The connector pins are 0.051" shorter than Agilent, while still providing .30" insertion depth. The **EM1** uses a US Digital designed codewheel with 2 tracks rather than 3 tracks for index versions. US Digital's **EM1** offers custom and special resolutions.

Ordering Information:

- The part numbers below do not include optical encoder disks or linear strips.
- Disks and linear strips must be ordered separately (*see the* ***DISK*** or ***LIN*** *data sheet*).

Pricing Levels per Module for 1" Disks:

CPR	Non-Index Part Number	Pricing Level	With Index Part Number	Pricing Level
32	-	-	EM1-1-32	2
50	HEDS-9100-S00	1	HEDS-9140-S00	2
96	HEDS-9100-C00	1	HEDS-9140-C00	2
100	HEDS-9100-C00	1	HEDS-9140-C00	2
110	HEDS-9100-C00	1	-	-
120	HEDS-9100-C00	1	-	-
192	HEDS-9100-E00	1	HEDS-9140-E00	2
200	HEDS-9100-E00	1	HEDS-9140-E00	2
250	HEDS-9100-F00	1	HEDS-9140-F00	2
256	HEDS-9100-F00	1	HEDS-9140-F00	2
360	HEDS-9100-G00	1	HEDS-9140-G00	2
400	HEDS-9100-H00	1	HEDS-9140-H00	2
500	HEDS-9100-A00	1	HEDS-9140-A00	2
512	HEDS-9100-I00	1	HEDS-9140-I00	2
540	HEDS-9100-I00	1	-	-
720	-	-	EM1-1-720	3
900	-	-	EM1-1-900	3
1000	HEDS-9100-B00	2	EM1-1-1000	3
1016	HEDS-9100-J00	2	-	-
1024	HEDS-9100-J00	2	EM1-1-1024	3
1250	-	-	EM1-1-1250	3

Pricing Levels per Module for 2" Disks:

CPR	Non-Index Part Number	Pricing Level	With Index Part Number	Pricing Level
64	-	-	EM1-2-64	2
100	HEDS-9100-S00	1	HEDS-9140-S00	2
200	HEDS-9100-C00	1	HEDS-9140-C00	2
400	HEDS-9100-E00	1	HEDS-9140-E00	2
500	HEDS-9000-A00	1	HEDS-9140-F00	2
512	HEDS-9000-A00	1	-	-
1000	HEDS-9000-B00	1	HEDS-9040-B00	2
1024	HEDS-9000-J00	1	HEDS-9040-J00	2
1800	-	-	EM1-2-1800	3
2000	HEDS-9000-T00	2	HEDS-9040-T00	2
2048	HEDS-9000-U00	2	HEDS-9040-T00	2
2500	EM1-2-2500-N	3	EM1-2-2500	3

Pricing Levels per Module for Linear Strips:

CPR	Non-Index Part Number	Pricing Level	With Index Part Number	Pricing Level
120	-	-	EM1-0-120	2
125	-	-	EM1-0-125	2
127	-	-	EM1-0-127	2
150	-	-	EM1-0-150	2
180	HEDS-9200-Q00	2	-	-
200	-	-	EM1-0-200	2
250	-	-	EM1-0-250	2
300	HEDS-9200-300	2	-	-
360	HEDS-9200-360	2	-	-
500	-	-	EM1-0-500	4

Prices:

Level 1:
$26.25 / 1
$23.35 / 10
$19.92 / 50
$17.65 / 100

Level 2:
$29.40 / 1
$26.16 / 10
$22.30 / 50
$19.76 / 100

Level 3:
$32.55 / 1
$28.96 / 10
$24.70 / 50
$21.88 / 100

Level 4:
$35.70 / 1
$31.76 / 10
$27.09 / 50
$24.00 / 100

Technical Data, Rev. 08.27.07, August 2007

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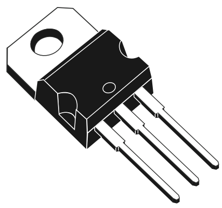
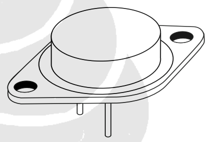
LM123/LM223
LM323

THREE-TERMINAL 3A-5V POSITIVE VOLTAGE REGULATORS

- OUTPUT CURRENT: 3A
- INTERNAL CURRENT AND THERMAL LIMITING
- TYPICAL OUTPUT IMPEDANCE: 0.01Ω
- MINIMUM INPUT VOLTAGE: 7.5V
- POWER DISSIPATION: 30W



TO-220



TO-3

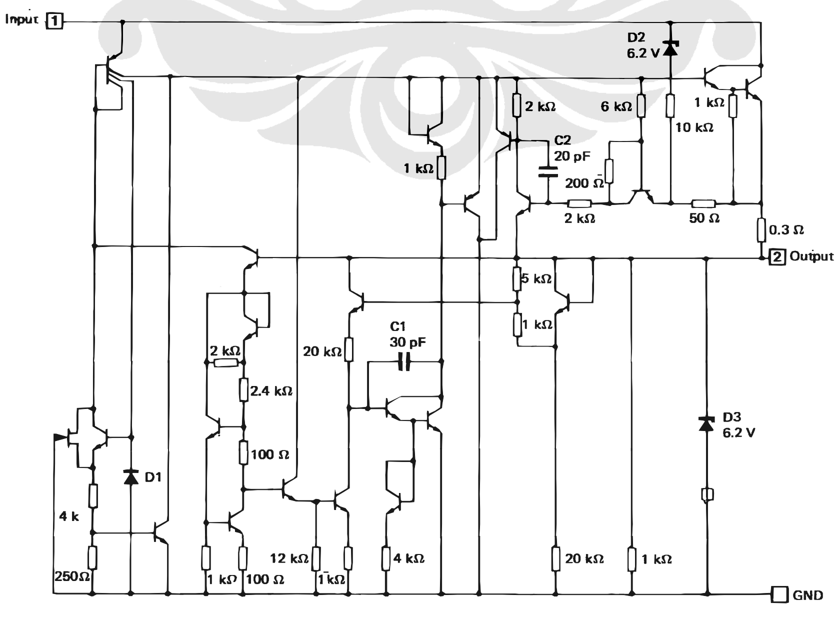
DESCRIPTION

The LM123, LM223, LM323 are three-terminal positive voltage regulators with a preset 5V output and a load driving capability of 3A. New circuit design and processing techniques are used to provide the high output current without sacrificing the regulation characteristics of lower current devices.

The 3A regulator is virtually blowout proof.

Current limiting, power limiting and thermal shut-down provide the same high level of reliability obtained with these techniques in the LM209, 1A regulator. An overall worst case specification for the combined effects of input voltage, load current, ambient temperature, and power dissipation ensure that the LM123, LM223, LM323 will perform satisfactorily as a system element.

SCHEMATIC DIAGRAM



ABSOLUTE MAXIMUM RATINGS

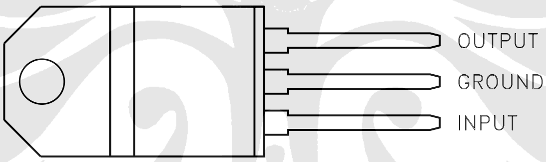
Symbol	Parameter²		Value	Unit
V_I	Input Voltage		20	V
I_O	Output Current		Internally Limited	
P_{tot}	Power Dissipation		Internally Limited	
T_{stg}	Storage Temperature Range		-65 to 150	°C
T_{oper}	Operating Junction Temperature Range	LM123	-55 to 150	°C
		LM223	-25 to 125	
		LM323	0 to 125	

Absolute Maximum Ratings are those values beyond which damage to the device may occur. Functional operation under these condition is not implied.

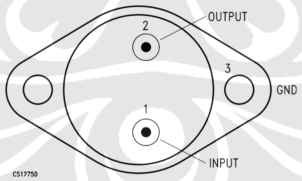
THERMAL DATA

Symbol	Parameter	TO-220	TO-3	Unit
$R_{thj\text{-}case}$	Thermal Resistance Junction-case Max	3	2	°C/W
$R_{thj\text{-}amb}$	Thermal Resistance Junction-ambient Max	50	35	°C/W

CONNECTION DIAGRAM (top view)



TO-220



TO-3

ORDERING CODES

TYPE	TO-220	TO-3	TEMPERATURE RANGE
LM123		LM123K	-55°C to 150°C
LM223		LM223K	-25°C to 150°C
LM323	LM323T	LM323K	0°C to 125°C

ELECTRICAL CHARACTERISTICS OF LM123/LM223 (T_J = -55 to 150°C for LM123, T_J = -25 to 150°C for LM223 unless otherwise specified).

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
V_O	Output Voltage Range (Note 2)	T_a = 25°C, V_I = 7.5 V, I_O = 0	4.7	5	5.3	V
V_O	Output Voltage Range (Note 2)	$T_J = T_{min}$ to T_{max} $P \leq P_{max}$ V_I = 7.5 to 15 V I_O = 0 to 3 A	4.6		5.4	V
K_{VI}	Line Regulation (Note 3)	V_I = 7.5 to 15 V T_J = 25°C		5	25	mV
K_{VO}	Load Regulation (Note 3)	I_O = 0 to 3 A V_I = 7.5 V T_J = 25°C		25	100	mV
I_{IB}	Quiescent Current	V_I = 7.5 to 15 V I_O = 0 to 3 A		12	20	mA
V_{NO}	Output Noise Voltage	T_a = 25°C f = 10 Hz to 100 KHz		40		μV_{rms}
I_{OS}	Short Circuit Current Limit	V_I = 15 V T_J = 25°C		3	4.5	A
		V_I = 7.5 V T_J = 25°C		4	5	
K_{VH}	Long Term Stability				35	mV

Notes: 1. Although power dissipation is internally limited, specifications apply only for P ≤ 30W.
2. Selected devices with tightened tolerance output voltage available.
3. Load and line regulation are specified at constant junction temperature. Pulse testing is required with a pulse width ≤ 1ms and duty cycle ≤ 5%.

ELECTRICAL CHARACTERISTICS OF LM323 (T_J = 0 to 150°C, unless otherwise specified).

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
V_O	Output Voltage Range (Note 2)	T_a = 25°C, V_I = 7.5 V, I_O = 0	4.8	5	5.2	V
V_O	Output Voltage Range (Note 2)	$T_J = T_{min}$ to T_{max} $P \leq P_{max}$ V_I = 7.5 to 15 V I_O = 0 to 3 A	4.75		5.25	V
K_{VI}	Line Regulation (Note 3)	V_I = 7.5 to 15 V T_J = 25°C		5	25	mV
K_{VO}	Load Regulation (Note 3)	I_O = 0 to 3 A V_I = 7.5 V T_J = 25°C		25	100	mV
I_{IB}	Quiescent Current	V_I = 7.5 to 15 V I_O = 0 to 3 A		12	20	mA
V_{NO}	Output Noise Voltage	T_a = 25°C f = 10 Hz to 100 KHz		40		μV_{rms}
I_{OS}	Short Circuit Current Limit	V_I = 15 V T_J = 25°C		3	4.5	A
		V_I = 7.5 V T_J = 25°C		4	5	
K_{VH}	Long Term Stability				35	mV

Notes: 1. Although power dissipation is internally limited, specifications apply only for P ≤ 30W.
2. Selected devices with tightened tolerance output voltage available.
3. Load and line regulation are specified at constant junction temperature. Pulse testing is required with a pulse width ≤ 1ms and duty cycle ≤ 5%.

Figure 1 : Output Noise Voltage

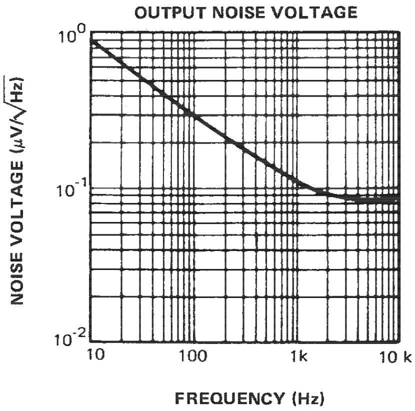


Figure 2 : Output Impedance

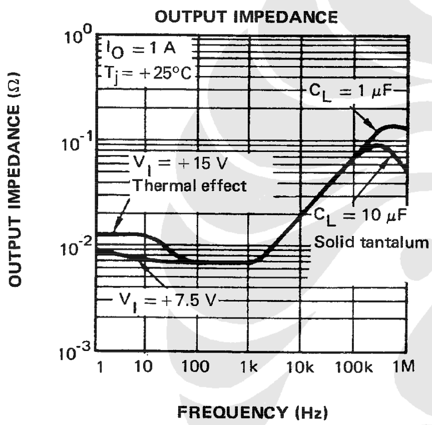


Figure 3 : Peak Available Output Current

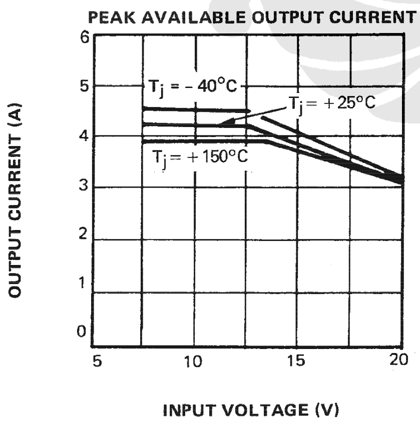


Figure 4 : Short Circuit Current

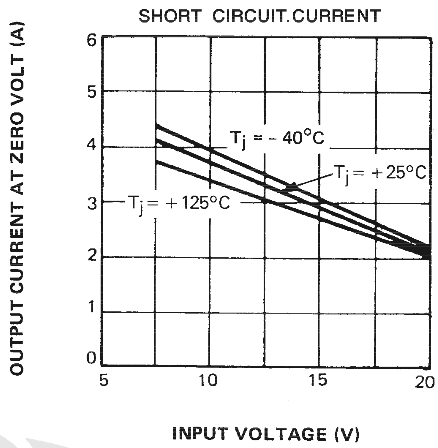


Figure 5 : Ripple Rejection

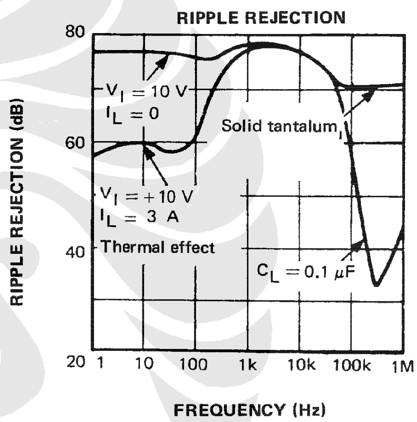


Figure 6 : Dropout Voltage

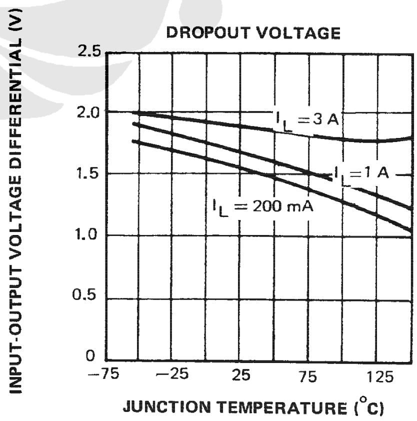


Figure 7 : Line Transient Response

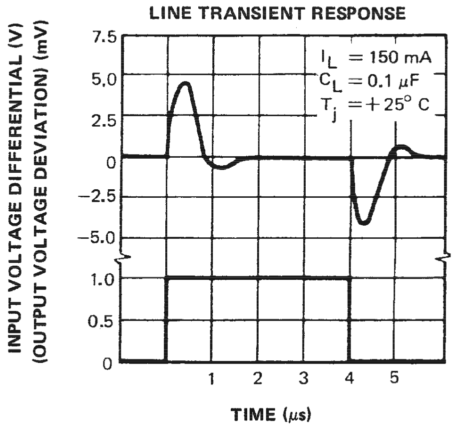


Figure 9 : Quiescent Current

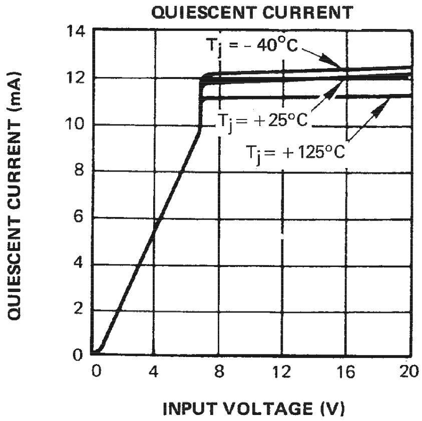


Figure 8 : Output Voltage

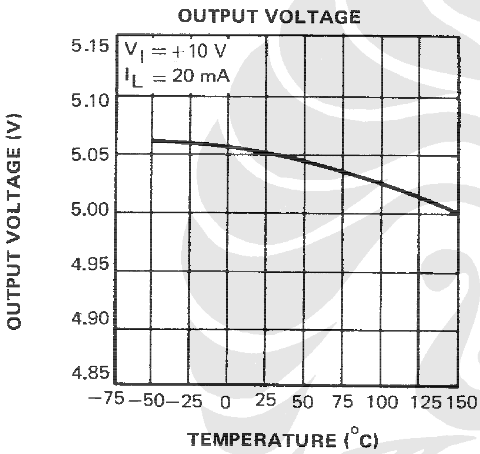
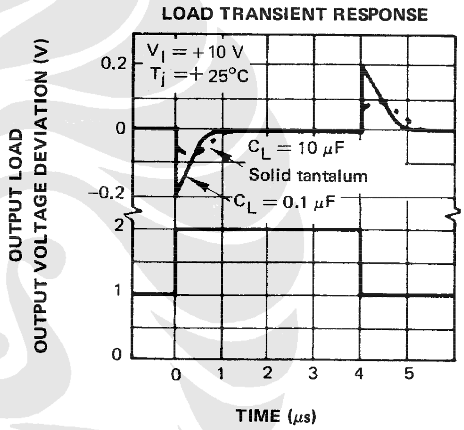
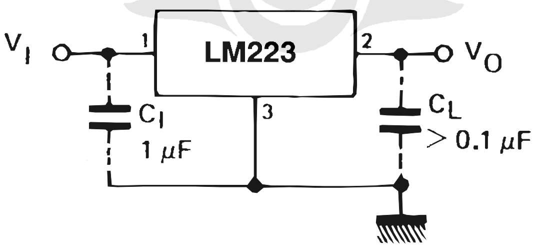


Figure 10 : Load Transient Response



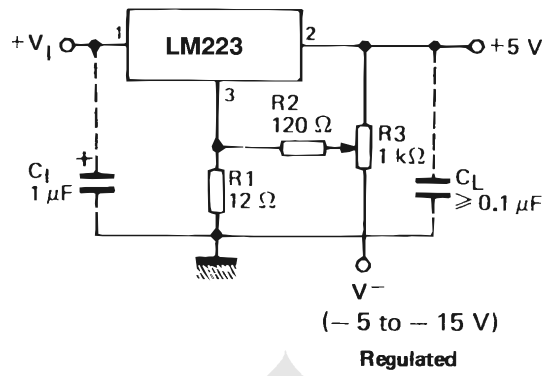
TYPICAL APPLICATION

BASIC 3A REGULATOR

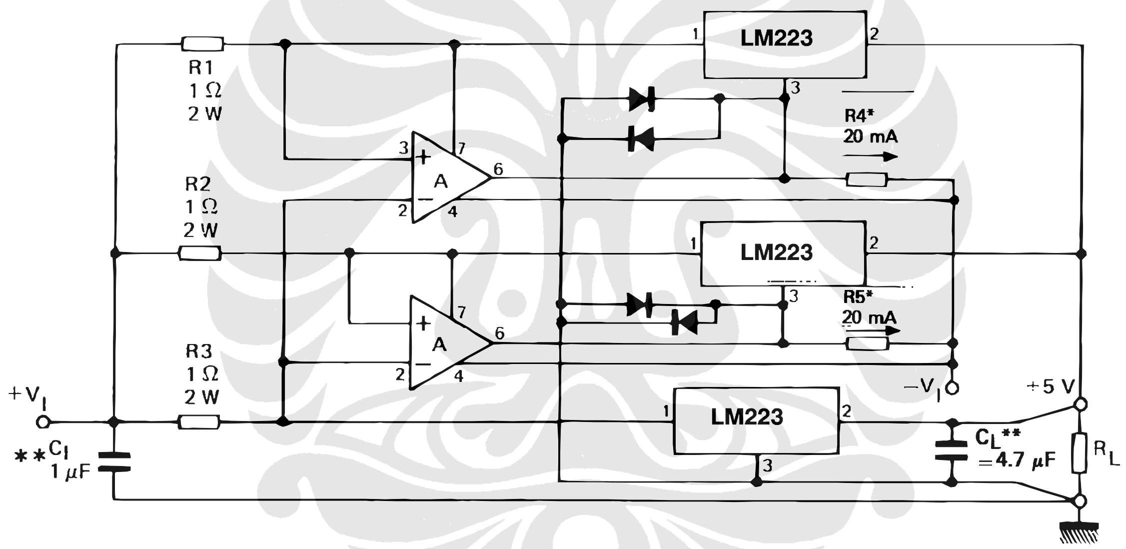


C_1 = Required if regulator is distant from filter capacitors.
C_L = Regulator is stable with no load capacitor into resistive loads.

TRIMING OUTPUT TO 5V

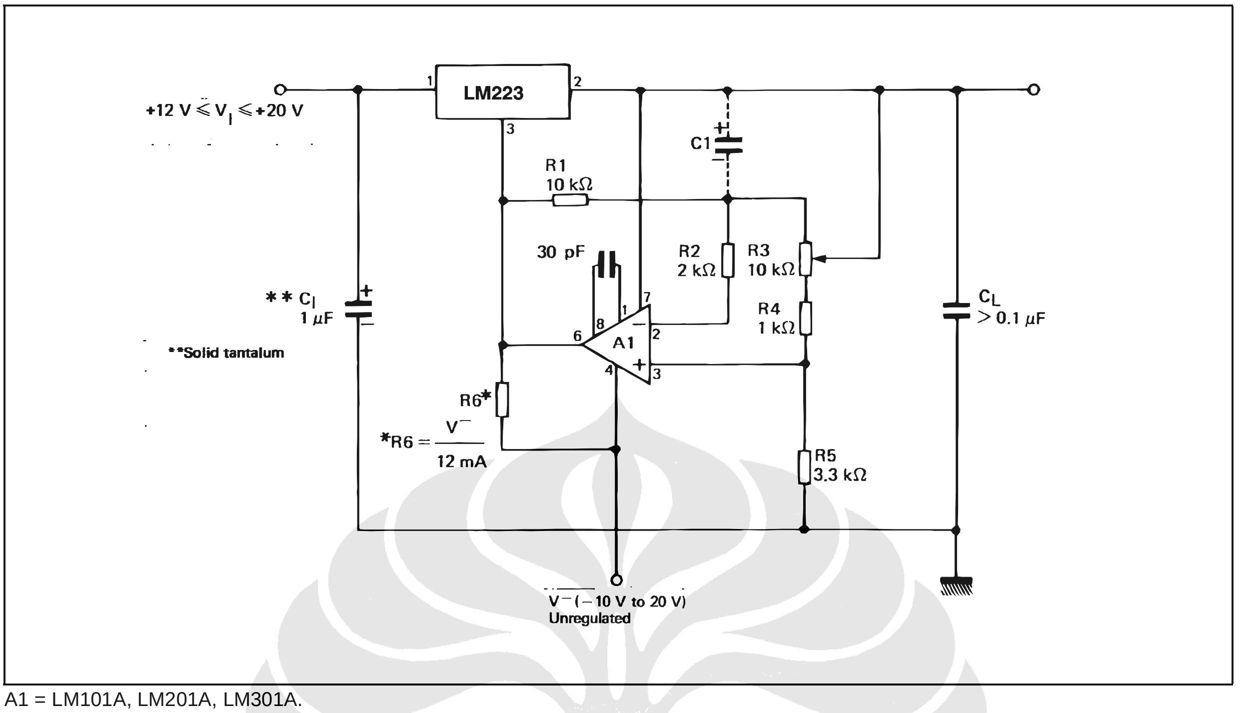


10A REGULATOR WITH COMPLETE OVERLOAD PROTECTION



* Selected for 20 mA current from unregulated negative supply.
** Solid tantalum.
A = LM101A, LM201A, LM301A.

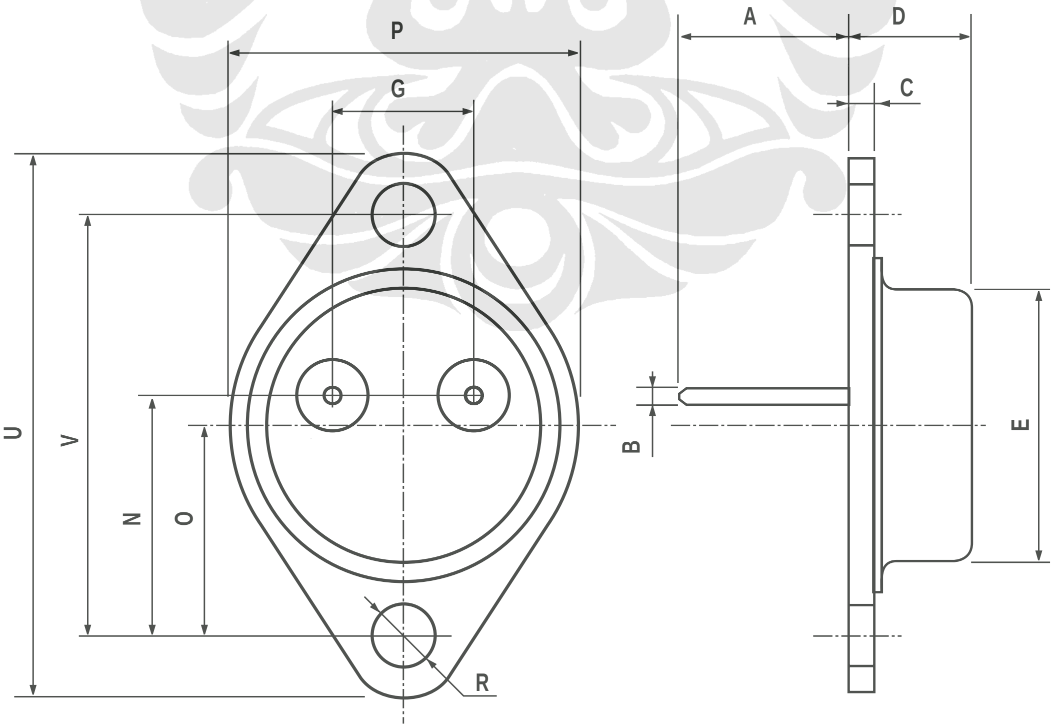
ADJUSTABLE REGULATOR 0 - 10V/3A



A1 = LM101A, LM201A, LM301A.
CI = 2µF optional - improves ripple rejection, noise and transient response.

TO-3 MECHANICAL DATA

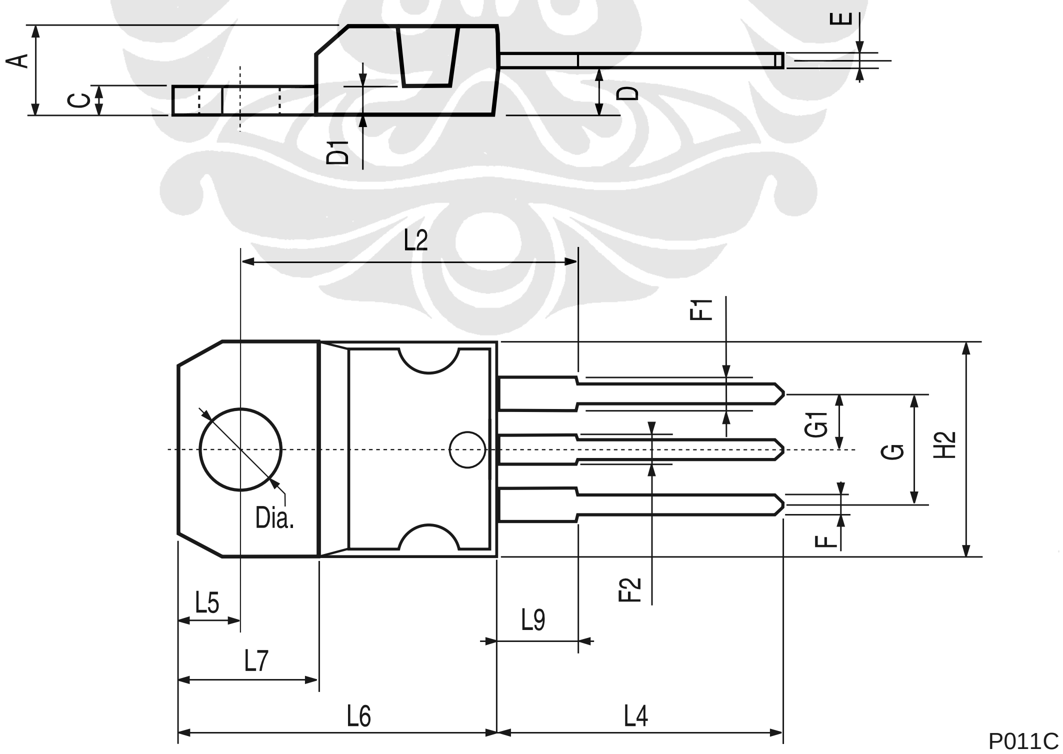
DIM.	mm.			inch		
	MIN.	TYP	MAX.	MIN.	TYP.	MAX.
A		11.85			0.466	
B	0.96	1.05	1.10	0.037	0.041	0.043
C			1.70			0.066
D			8.7			0.342
E			20.0			0.787
G		10.9			0.429	
N		16.9			0.665	
P			26.2			1.031
R	3.88		4.09	0.152		0.161
U			39.5			1.555
V		30.10			1.185	



P003C/C

TO-220 MECHANICAL DATA

DIM.	mm.			inch		
	MIN.	TYP	MAX.	MIN.	TYP.	MAX.
A	4.40		4.60	0.173		0.181
C	1.23		1.32	0.048		0.051
D	2.40		2.72	0.094		0.107
D1		1.27			0.050	
E	0.49		0.70	0.019		0.027
F	0.61		0.88	0.024		0.034
F1	1.14		1.70	0.044		0.067
F2	1.14		1.70	0.044		0.067
G	4.95		5.15	0.194		0.203
G1	2.4		2.7	0.094		0.106
H2	10.0		10.40	0.393		0.409
L2		16.4			0.645	
L4	13.0		14.0	0.511		0.551
L5	2.65		2.95	0.104		0.116
L6	15.25		15.75	0.600		0.620
L7	6.2		6.6	0.244		0.260
L9	3.5		3.93	0.137		0.154
DIA.	3.75		3.85	0.147		0.151



National Semiconductor

May 1998

LM138/LM338
5-Amp Adjustable Regulators

General Description

The LM138 series of adjustable 3-terminal positive voltage regulators is capable of supplying in excess of 5A over a 1.2V to 32V output range. They are exceptionally easy to use and require only 2 resistors to set the output voltage. Careful circuit design has resulted in outstanding load and line regulation — comparable to many commercial power supplies. The LM138 family is supplied in a standard 3-lead transistor package.

A unique feature of the LM138 family is time-dependent current limiting. The current limit circuitry allows peak currents of up to 12A to be drawn from the regulator for short periods of time. This allows the LM138 to be used with heavy transient loads and speeds start-up under full-load conditions. Under sustained loading conditions, the current limit decreases to a safe value protecting the regulator. Also included on the chip are thermal overload protection and safe area protection for the power transistor. Overload protection remains functional even if the adjustment pin is accidentally disconnected.

Normally, no capacitors are needed unless the device is situated more than 6 inches from the input filter capacitors in which case an input bypass is needed. An output capacitor can be added to improve transient response, while bypassing the adjustment pin will increase the regulator's ripple rejection.

Besides replacing fixed regulators or discrete designs, the LM138 is useful in a wide variety of other applications. Since the regulator is "floating" and sees only the input-to-output differential voltage, supplies of several hundred volts can be regulated as long as the maximum input to output differential is not exceeded, i.e., do not short-circuit output to ground. The part numbers in the LM138 series which have a K suffix are packaged in a standard Steel TO-3 package, while those with a T suffix are packaged in a TO-220 plastic package. The LM138 is rated for $-55^{\circ}C \leq T_J \leq +150^{\circ}C$, and the LM338 is rated for $0^{\circ}C \leq T_J \leq +125^{\circ}C$.

Features

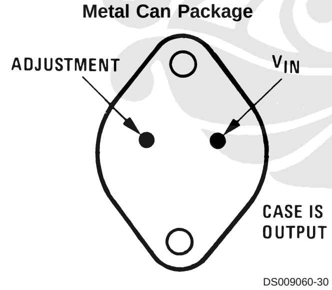
- Guaranteed 7A peak output current
- Guaranteed 5A output current
- Adjustable output down to 1.2V
- Guaranteed thermal regulation
- Current limit constant with temperature
- P^+ Product Enhancement tested
- Output is short-circuit protected

Applications

- Adjustable power supplies
- Constant current regulators
- Battery chargers

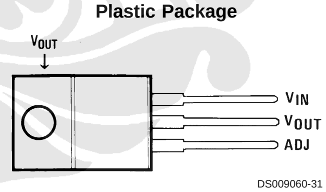
Connection Diagrams (See Physical Dimension section for further information)

(TO-3 STEEL)
Metal Can Package



Bottom View
Order Number LM138K STEEL or LM338K STEEL
See NS Package Number K02A

(TO-220)
Plastic Package



Front View
Order Number LM338T
See NS Package Number T03B

Absolute Maximum Ratings (Note 1)

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

(Note 4)

Power Dissipation	Internally limited
Input/Output Voltage Differential	+40V, −0.3V
Storage Temperature	−65˚C to +150˚C
Lead Temperature	
Metal Package (Soldering, 10 seconds)	300˚C
Plastic Package (Soldering, 4 seconds)	260˚C
ESD Tolerance	TBD

Operating Temperature Range

LM138	$-55˚C \leq T_J \leq +150˚C$
LM338	$0˚C \leq T_J \leq +125˚C$

Electrical Characteristics

Specifications with standard type face are for T_J = 25˚C, and those with **boldface type** apply over **full Operating Temperature Range.** Unless otherwise specified, $V_{IN} - V_{OUT}$ = 5V; and I_{OUT} = 10 mA. (Note 2)

Symbol	Parameter	Conditions	LM138			Units
			Min	Typ	Max	
V_{REF}	Reference Voltage	$3V \leq (V_{IN} - V_{OUT}) \leq 35V$, $10 mA \leq I_{OUT} \leq 5A$, $P \leq 50W$	**1.19**	**1.24**	**1.29**	V
V_{RLINE}	Line Regulation	$3V \leq (V_{IN} - V_{OUT}) \leq 35V$ (Note 3)		0.005	0.01	%/V
				0.02	**0.04**	%/V
V_{RLOAD}	Load Regulation	$10 mA \leq I_{OUT} \leq 5A$ (Note 3)		0.1	0.3	%
				0.3	**0.6**	%
	Thermal Regulation	20 ms Pulse		0.002	0.01	%/W
I_{ADJ}	Adjustment Pin Current			**45**	**100**	µA
ΔI_{ADJ}	Adjustment Pin Current Change	$10 mA \leq I_{OUT} \leq 5A$, $3V \leq (V_{IN} - V_{OUT}) \leq 35V$		**0.2**	**5**	µA
$\Delta V_{R/T}$	Temperature Stability	$T_{MIN} \leq T_J \leq T_{MAX}$		**1**		%
I_{LOAD}(Min)	Minimum Load Current	$V_{IN} - V_{OUT}$ = 35V		**3.5**	**5**	mA
I_{CL}	Current Limit	$V_{IN} - V_{OUT} \leq 10V$				
		DC	**5**	**8**		A
		0.5 ms Peak	**7**	**12**		A
		$V_{IN} - V_{OUT}$ = 30V		1	1	A
V_N	RMS Output Noise, % of V_{OUT}	10 Hz ≤ f ≤ 10 kHz		0.003		%
$\frac{\Delta V_R}{\Delta V_{IN}}$	Ripple Rejection Ratio	V_{OUT} = 10V, f = 120 Hz, C_{ADJ} = 0 µF		**60**		dB
		V_{OUT} = 10V, f = 120 Hz, C_{ADJ} = 10 µF	**60**	**75**		dB
	Long-Term Stability	T_J = 125˚C, 1000 Hrs		0.3	1	%
θ_{JC}	Thermal Resistance, Junction to Case	K Package			1	˚C/W
θ_{JA}	Thermal Resistance, Junction to Ambient (No Heat Sink)	K Package		35		˚C/W

Electrical Characteristics

Symbol	Parameter	Conditions	LM338			Units
			Min	Typ	Max	
V_{REF}	Reference Voltage	$3V \leq (V_{IN} - V_{OUT}) \leq 35V$, $10 mA \leq I_{OUT} \leq 5A$, $P \leq 50W$	**1.19**	**1.24**	**1.29**	V
V_{RLINE}	Line Regulation	$3V \leq (V_{IN} - V_{OUT}) \leq 35V$ (Note 3)		0.005	0.03	%/V
				0.02	**0.06**	%/V
V_{RLOAD}	Load Regulation	$10 mA \leq I_{OUT} \leq 5A$ (Note 3)		0.1	0.5	%
				0.3	**1**	%
	Thermal Regulation	20 ms Pulse		0.002	0.02	%/W
I_{ADJ}	Adjustment Pin Current			**45**	**100**	µA
ΔI_{ADJ}	Adjustment Pin Current Change	$10 mA \leq I_{OUT} \leq 5A$, $3V \leq (V_{IN} - V_{OUT}) \leq 35V$		**0.2**	**5**	µA

Electrical Characteristics (Continued)

Symbol	Parameter	Conditions	LM338 Min	LM338 Typ	LM338 Max	Units
$\Delta V_{R/T}$	Temperature Stability	$T_{MIN} \leq T_J \leq T_{MAX}$		**1**		%
I_{LOAD}(Min)	Minimum Load Current	$V_{IN} - V_{OUT}$ = 35V		**3.5**	**10**	mA
I_{CL}	Current Limit	$V_{IN} - V_{OUT} \leq$ 10V				
		DC	**5**	**8**		A
		0.5 ms Peak	**7**	**12**		A
		$V_{IN} - V_{OUT}$ = 30V			1	A
V_N	RMS Output Noise, % of V_{OUT}	10 Hz ≤ f ≤ 10 kHz		0.003		%
$\frac{\Delta V_R}{\Delta V_{IN}}$	Ripple Rejection Ratio	V_{OUT} = 10V, f = 120 Hz, C_{ADJ} = 0 µF		**60**		dB
		V_{OUT} = 10V, f = 120 Hz, C_{ADJ} = 10 µF	**60**	**75**		dB
	Long-Term Stability	T_J = 125˚C, 1000 hrs		0.3	1	%
θ_{JC}	Thermal Resistance	K Package			1	˚C/W
	Junction to Case	T Package			4	˚C/W
θ_{JA}	Thermal Resistance, Junction to	K Package		35		˚C/W
	Ambient (No Heat Sink)	T Package		50		˚C/W

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

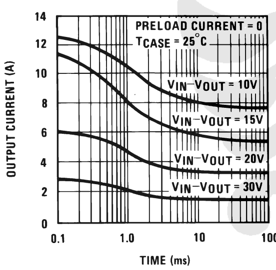
Note 2: These specifications are applicable for power dissipations up to 50W for the TO-3 (K) package and 25W for the TO-220 (T) package. Power dissipation is guaranteed at these values up to 15V input-output differential. Above 15V differential, power dissipation will be limited by internal protection circuitry. All limits (i.e., the numbers in the Min. and Max. columns) are guaranteed to National's AOQL (Average Outgoing Quality Level).

Note 3: Regulation is measured at a constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specifications for thermal regulation.

Note 4: Refer to RETS138K drawing for military specifications of LM138K.

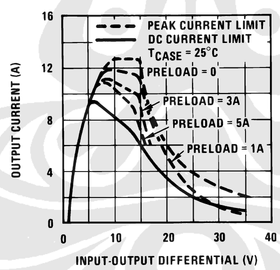
Typical Performance Characteristics

Current Limit



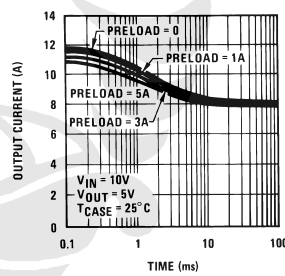
DS009060-32

Current Limit



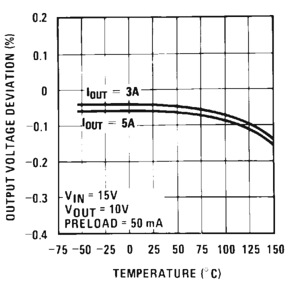
DS009060-33

Current Limit



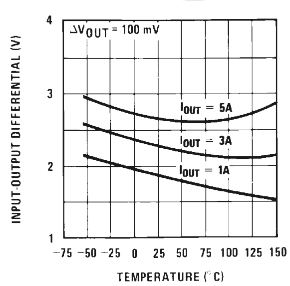
DS009060-34

Load Regulation



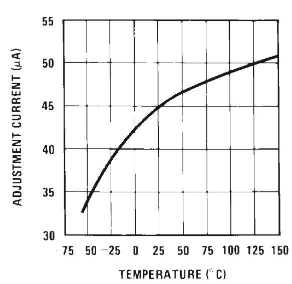
DS009060-35

Dropout Voltage



DS009060-36

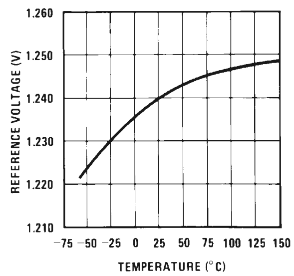
Adjustment Current



DS009060-37

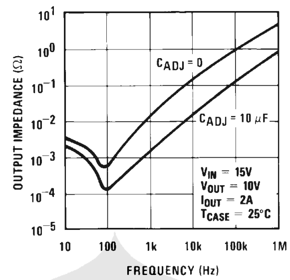
Typical Performance Characteristics (Continued)

Temperature Stability



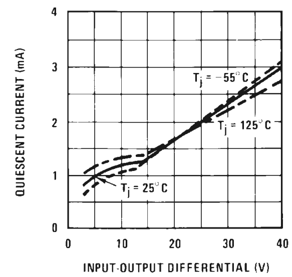
DS009060-38

Output Impedance



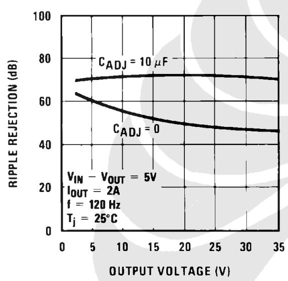
DS009060-39

Minimum Operating Current



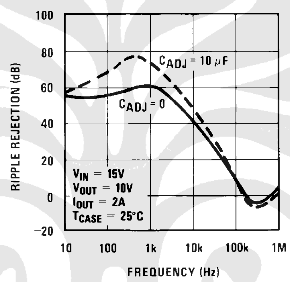
DS009060-40

Ripple Rejection



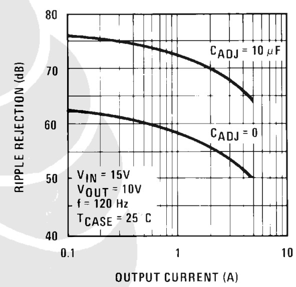
DS009060-41

Ripple Rejection



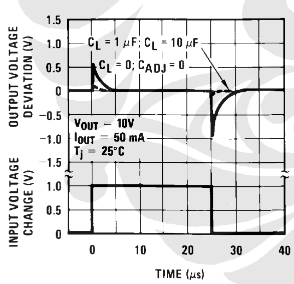
DS009060-42

Ripple Rejection



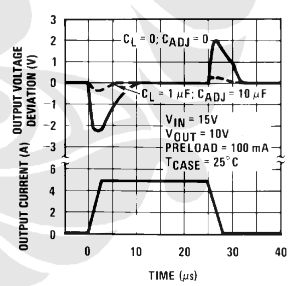
DS009060-43

Line Transient Response



DS009060-44

Load Transient Response



DS009060-45

Application Hints

In operation, the LM138 develops a nominal 1.25V reference voltage, V_{REF}, between the output and adjustment terminal. The reference voltage is impressed across program resistor R1 and, since the voltage is constant, a constant current I_1 then flows through the output set resistor R2, giving an output voltage of

$$V_{OUT} = V_{REF}\left(1 + \frac{R2}{R1}\right) + I_{ADJ}R2.$$

Application Hints (Continued)

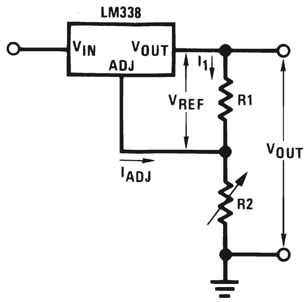


FIGURE 1.

Since the 50 µA current from the adjustment terminal represents an error term, the LM138 was designed to minimize I_{ADJ} and make it very constant with line and load changes. To do this, all quiescent operating current is returned to the output establishing a minimum load current requirement. If there is insufficient load on the output, the output will rise.

External Capacitors

An input bypass capacitor is recommended. A 0.1 µF disc or 1 µF solid tantalum on the input is suitable input bypassing for almost all applications. The device is more sensitive to the absence of input bypassiing when adjustment or output capacitors are used but the above values will eliminate the possiblity of problems.

The adjustment terminal can be bypassed to ground on the LM138 to improve ripple rejection. This bypass capacitor prevents ripple from being amplified as the output voltage is increased. With a 10 µF bypass capacitor 75 dB ripple rejection is obtainable at any output level. Increases over 20 µF do not appreciably improve the ripple rejection at frequencies above 120 Hz. If the bypass capacitor is used, it is sometimes necessary to include protection diodes to prevent the capacitor from discharging through internal low current paths and damaging the device.

In general, the best type of capacitors to use are solid tantalum. Solid tantalum capacitors have low impedance even at high frequencies. Depending upon capacitor construction, it takes about 25 µF in aluminum electrolytic to equal 1 µF solid tantalum at high frequencies. Ceramic capacitors are also good at high frequencies; but some types have a large decrease in capacitance at frequencies around 0.5 MHz. For this reason, 0.01 µF disc may seem to work better than a 0.1 µF disc as a bypass.

Although the LM138 is stable with no output capacitors, like any feedback circuit, certain values of external capacitance can cause excessive ringing. This occurs with values between 500 pF and 5000 pF. A 1 µF solid tantalum (or 25 µF aluminum electrolytic) on the output swamps this effect and insures stability.

Load Regulation

The LM138 is capable of providing extremely good load regulation but a few precautions are needed to obtain maximum performance. The current set resistor connected between the adjustment terminal and the output terminal (usually 240Ω) should be tied directly to the output of the regulator (case) rather than near the load. This eliminates line drops from appearing effectively in series with the reference and degrading regulation. For example, a 15V regulator with 0.05Ω resistance between the regulator and load will have a load regulation due to line resistance of 0.05Ω x I_L. If the set resistor is connected near the load the effective line resistance will be 0.05Ω (1 + R2/R1) or in this case, 11.5 times worse.

Figure 2 shows the effect of resistance between the regulator and 240Ω set resistor.

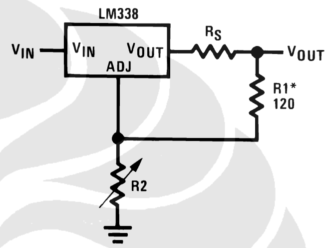


FIGURE 2. Regulator with Line Resistance in Output Lead

With the TO-3 package, it is easy to minimize the resistance from the case to the set resistor, by using 2 separate leads to the case. The ground of R2 can be returned near the ground of the load to provide remote ground sensing and improve load regulation.

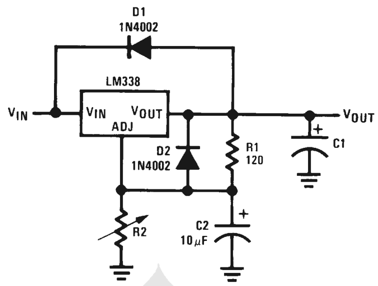
Protection Diodes

When external capacitors are used with *any* IC regulator it is sometimes necessary to add protection diodes to prevent the capacitors from discharging through low current points into the regulator. Most 20 µF capacitors have low enough internal series resistance to deliver 20A spikes when shorted. Although the surge is short, there is enough energy to damage parts of the IC.

When an output capacitor is connected to a regulator and the input is shorted, the output capacitor will discharge into the output of the regulator. The discharge current depends on the value of the capacitor, the output voltage of the regulator, and the rate of decrease of V_{IN}. In the LM138 this discharge path is through a large junction that is able to sustain 25A surge with no problem. This is not true of other types of positive regulators. For output capacitors of 100 µF or less at output of 15V or less, there is no need to use diodes.

The bypass capacitor on the adjustment terminal can discharge through a low current junction. Discharge occurs when *either* the input or output is shorted. Internal to the LM138 is a 50Ω resistor which limits the peak discharge current. No protection is needed for output voltages of 25V or less and 10 µF capacitance. *Figure 3* shows an LM138 with protection diodes included for use with outputs greater than 25V and high values of output capacitance.

Application Hints (Continued)



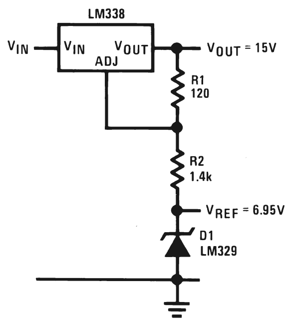
D1 protects against C1
D2 protects against C2

$$V_{OUT} = 1.25V\left(1 + \frac{R2}{R1}\right) + I_{ADJ}R2$$

FIGURE 3. Regulator with Protection Diodes

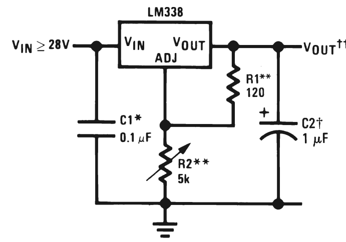
Typical Applications

Regulator and Voltage Reference



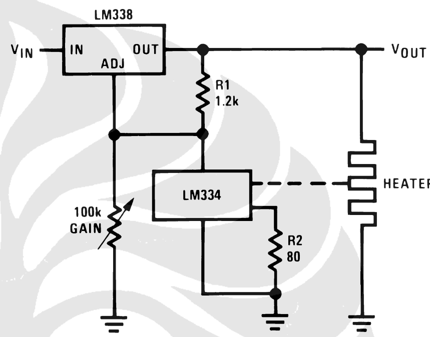
DS009060-3

1.2V–25V Adjustable Regulator



DS009060-1

Temperature Controller



DS009060-10

Full output current not available
at high input-output voltages

†Optional — improves transient response. Output capacitors in the range of 1 μF to 1000 μF of aluminum or tantalum electrolytic are commonly used to provide improved output impedance and rejection of transients.

*Needed if device is more than 6 inches from filter capacitors.

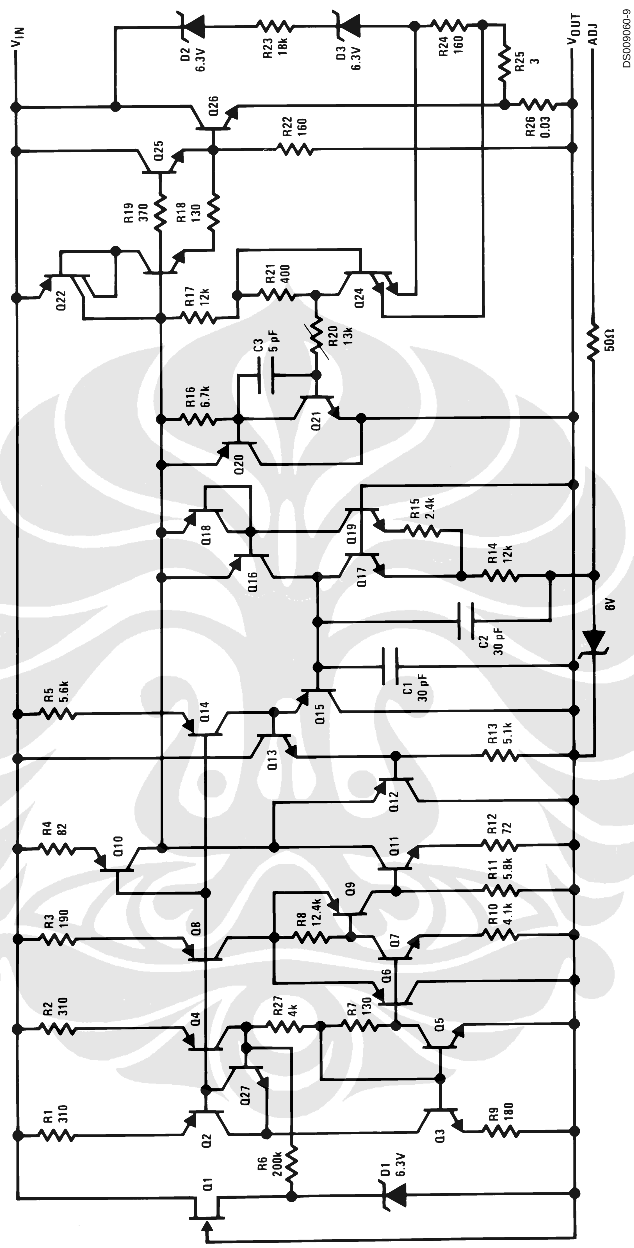
$$††V_{OUT} = 1.25V\left(1 + \frac{R2}{R1}\right) + I_{ADJ}(R_2)$$

**R1 = 240Ω for LM138. R1, R2 as an assembly can be ordered from Bourns:

MIL part no. 7105A-AT2-502

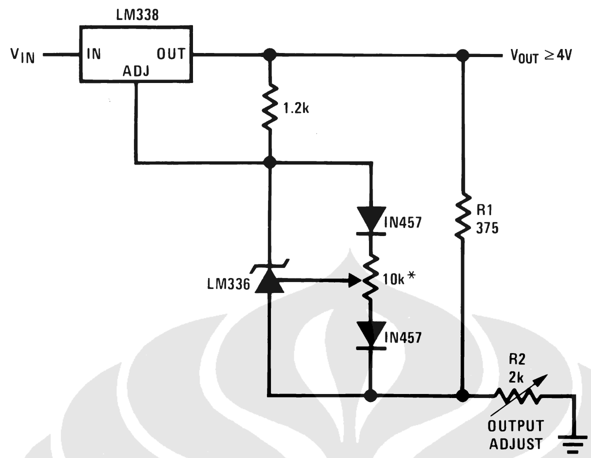
COMM part no. 7105A-AT7-502

Schematic Diagram



Typical Applications

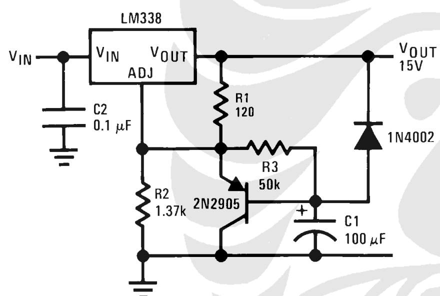
Precision Power Regulator with Low Temperature Coefficient



DS009060-12

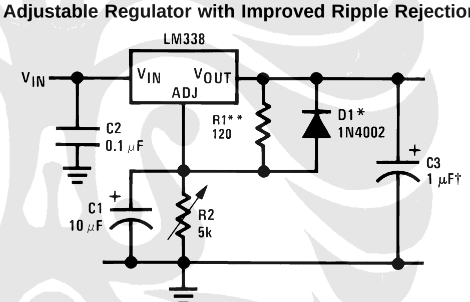
* Adjust for 3.75 across R1

Slow Turn-On 15V Regulator



DS009060-13

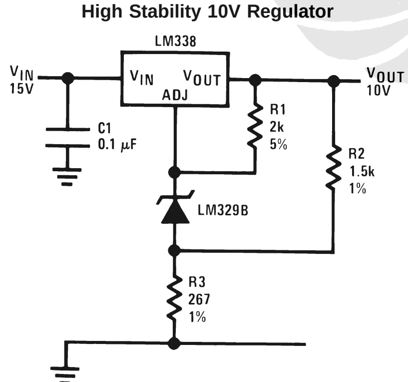
Adjustable Regulator with Improved Ripple Rejection



DS009060-14

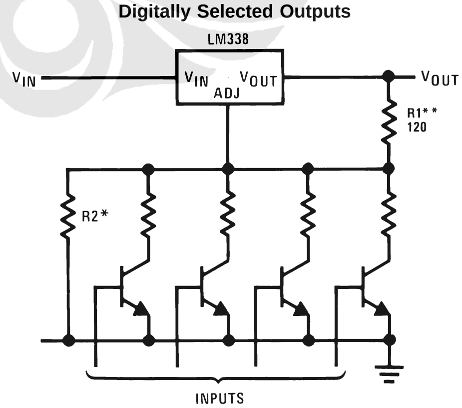
†Solid tantalum
*Discharges C1 if output is shorted to ground
**R1 = 240Ω for LM138

High Stability 10V Regulator



DS009060-15

Digitally Selected Outputs

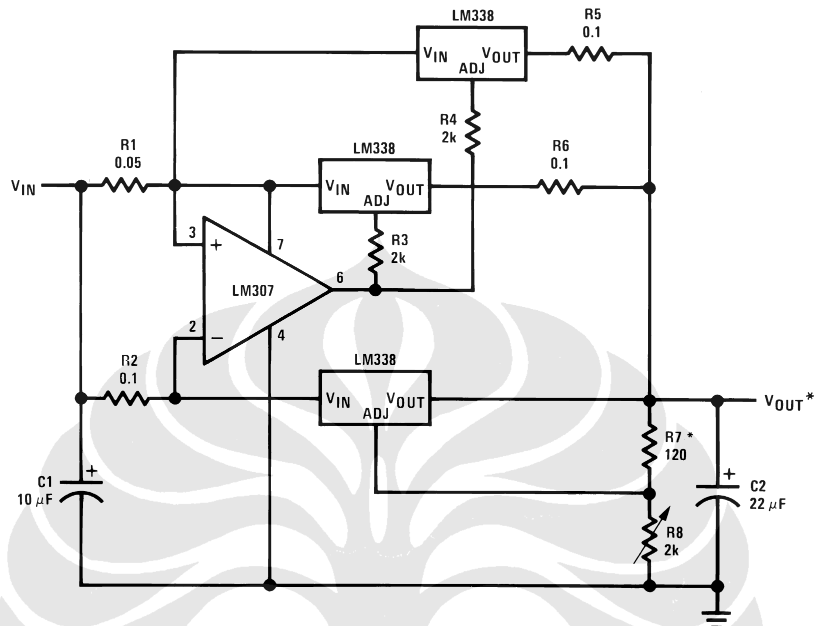


DS009060-16

*Sets maximum V_{OUT}
**R1 = 240Ω for LM138

Typical Applications (Continued)

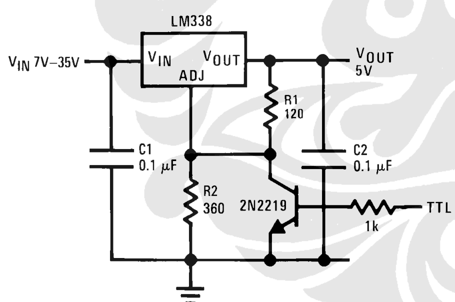
15A Regulator



DS009060-17

* Minimum load — 100 mA

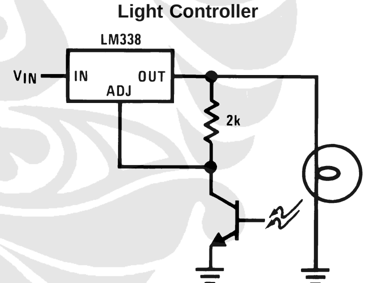
5V Logic Regulator with Electronic Shutdown**



DS009060-18

** Minimum output ≈ 1.2V

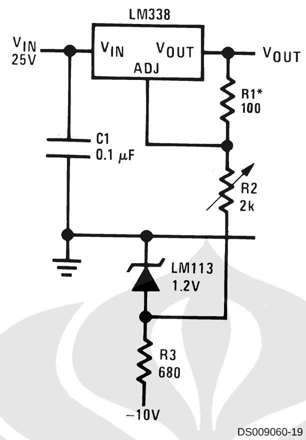
Light Controller



DS009060-11

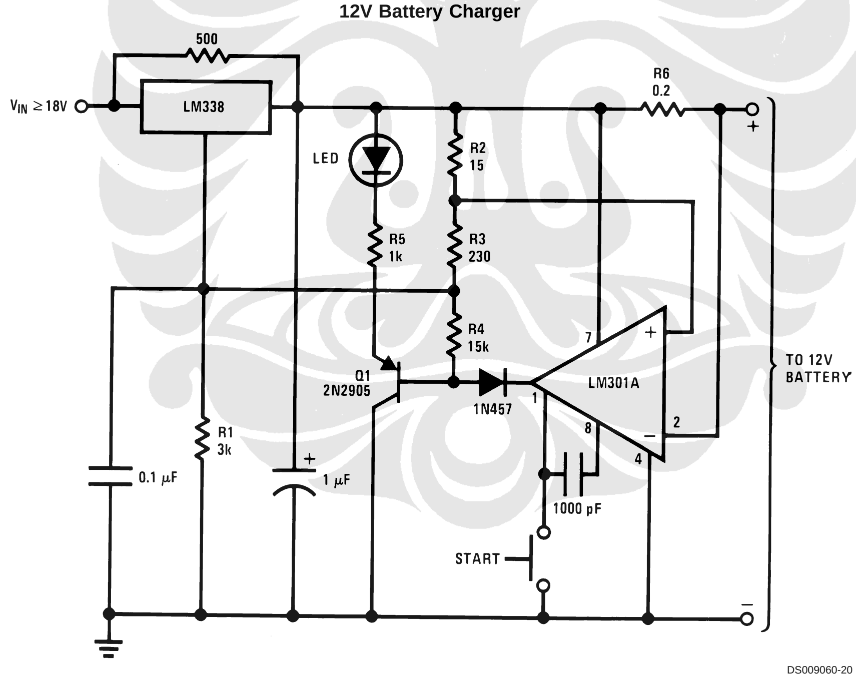
Typical Applications (Continued)

0 to 22V Regulator



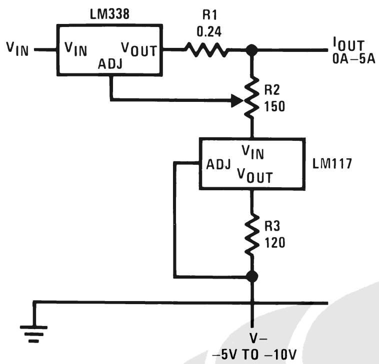
* R1 = 240Ω, R2 = 5k for LM138
Full output current not available
at high input-output voltages

12V Battery Charger



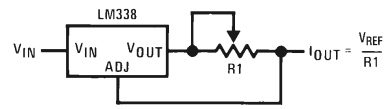
Typical Applications (Continued)

Adjustable Current Regulator



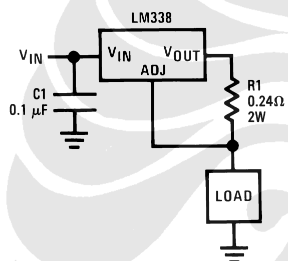
DS009060-21

Precision Current Limiter



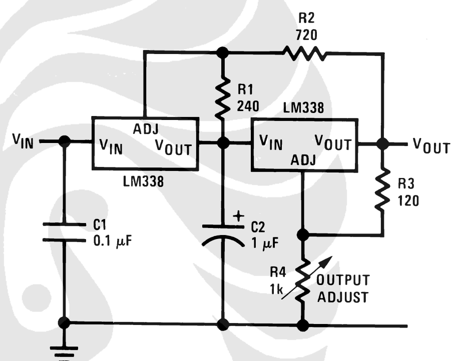
DS009060-22

5A Current Regulator



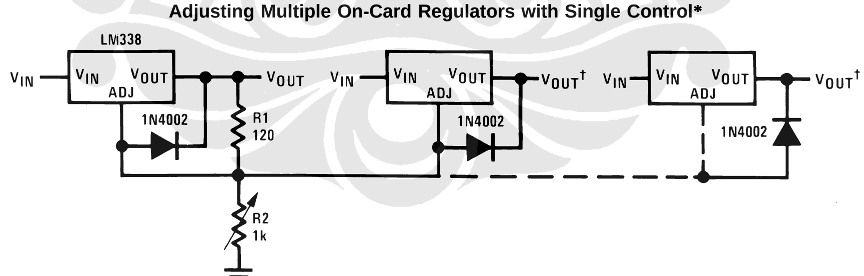
DS009060-23

Tracking Preregulator



DS009060-24

Adjusting Multiple On-Card Regulators with Single Control*

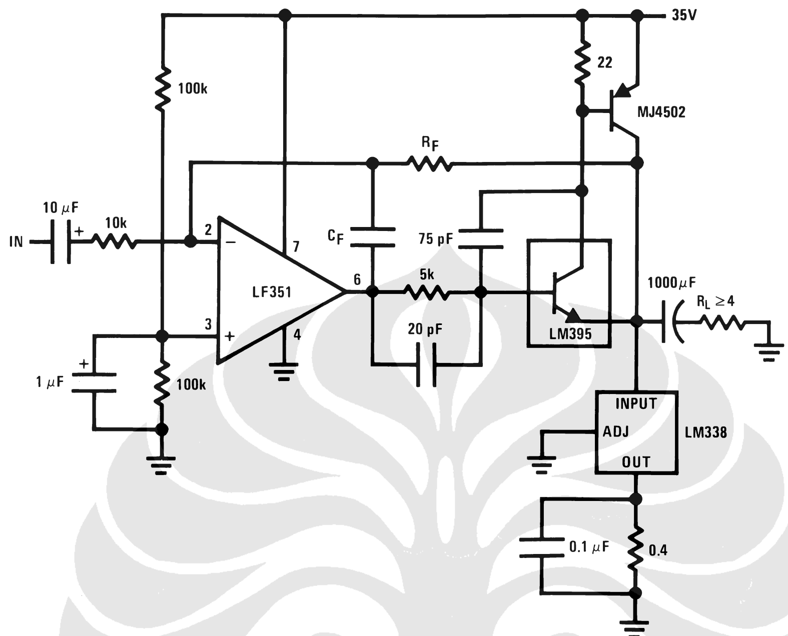


DS009060-25

† Minimum load — 10 mA
* All outputs within ±100 mV

Typical Applications (Continued)

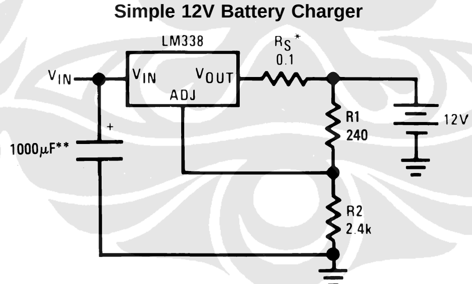
Power Amplifier



DS009060-27

$A_V = 1$, $R_F = 10k$, $C_F = 100$ pF
$A_V = 10$, $R_F = 100k$, $C_F = 10$ pF
Bandwidth ≥ 100 kHz
Distortion ≤ 0.1%

Simple 12V Battery Charger



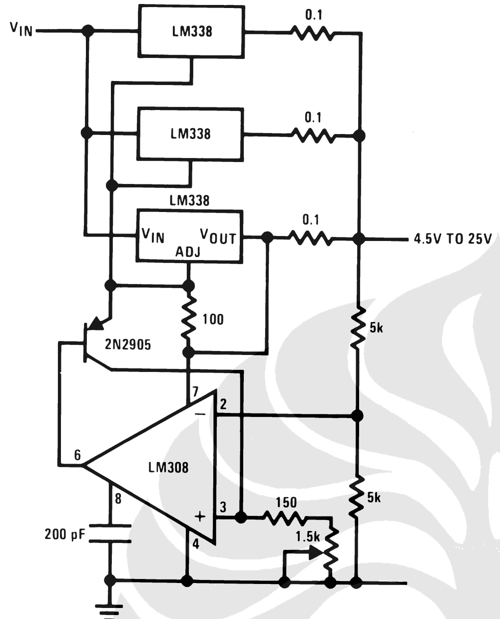
DS009060-28

*R_S—sets output impedance of charger $Z_{OUT} = R_S\left(1 + \frac{R2}{R1}\right)$

Use of R_S allows low charging rates with fully charged battery.
**The 1000 µF is recommended to filter out input transients

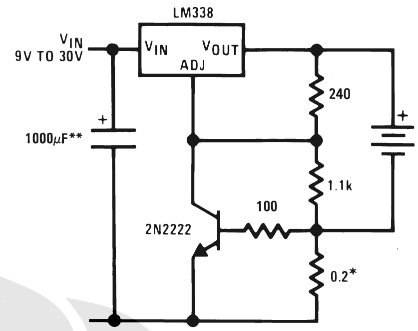
Typical Applications (Continued)

Adjustable 15A Regulator



DS009060-26

Current Limited 6V Charger

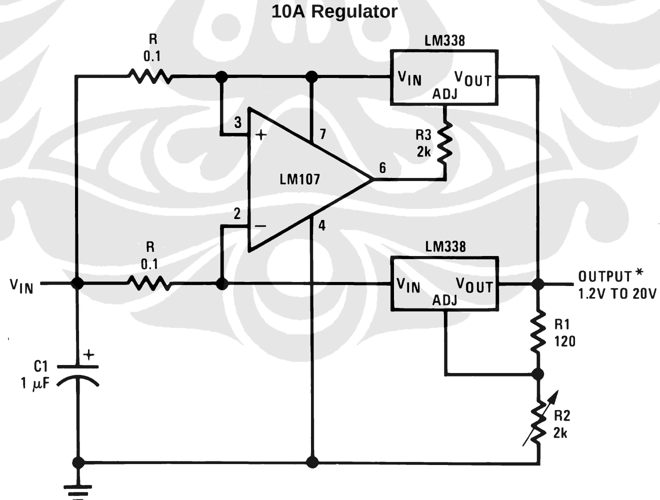


DS009060-29

* Set max charge current to 3A

** THE 1000 µF is recommended to filter out input transients.

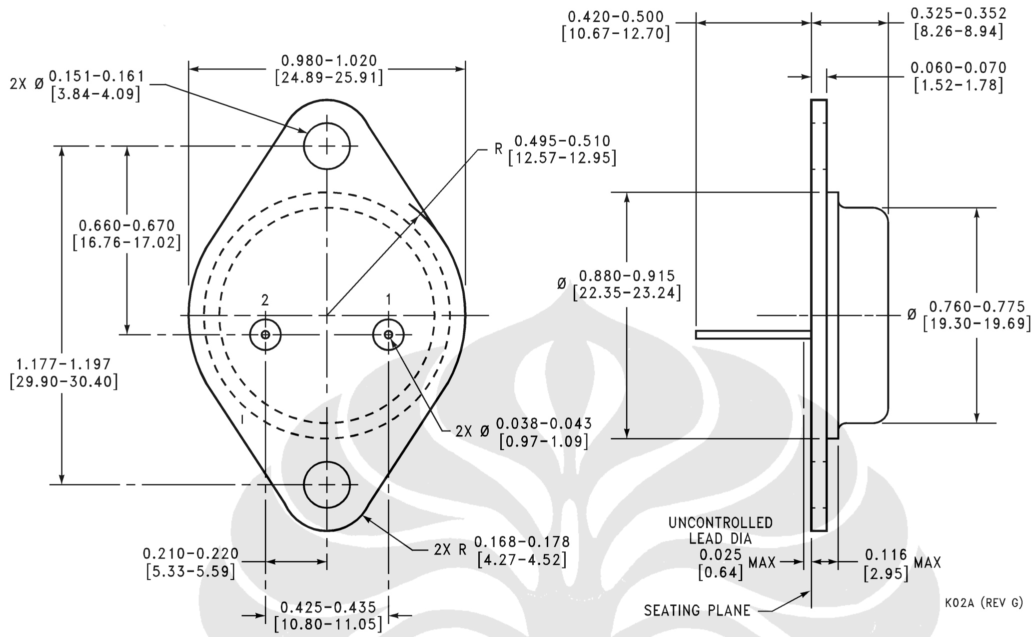
10A Regulator



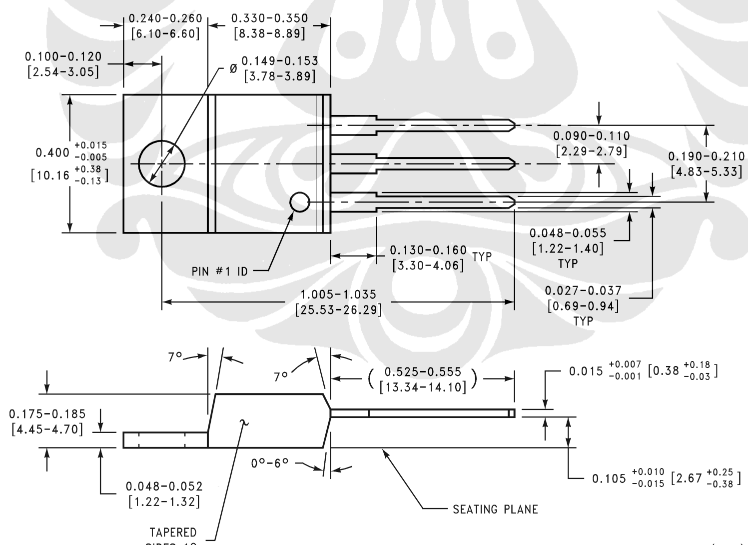
DS009060-2

* Minimum load — 100 mA

Physical Dimensions inches (millimeters) unless otherwise noted



2 Lead TO-3 Metal Can Package (K)
Order Number LM138K or LM338K STEEL
NS Package Number K02A



3 Lead Molded TO-220 (T)
Order Number LM338T
NS Package Number T03B

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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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National Semiconductor

August 2000

LM124/LM224/LM324/LM2902
Low Power Quad Operational Amplifiers

General Description

The LM124 series consists of four independent, high gain, internally frequency compensated operational amplifiers which were designed specifically to 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.

Application areas include transducer amplifiers, DC gain blocks and all the conventional op amp circuits which now can be more easily implemented in single power supply systems. For example, the LM124 series can be directly operated off of the standard +5V power supply voltage which is used in digital systems and will easily provide the required interface electronics without requiring the additional ±15V power supplies.

Unique Characteristics

- In the linear mode the input common-mode voltage range includes ground and the output voltage can also swing to ground, even though operated from only a single power supply voltage
- The unity gain cross frequency is temperature compensated
- The input bias current is also temperature compensated

Advantages

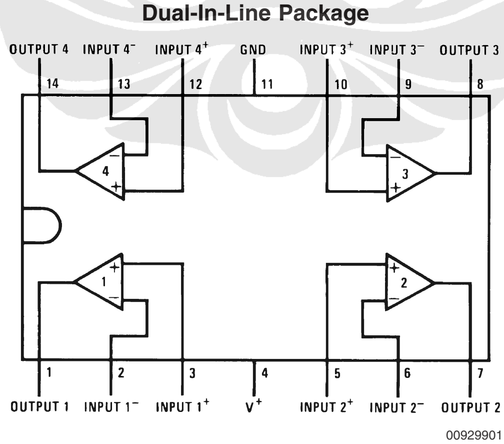
- Eliminates need for dual supplies
- Four internally compensated op amps in a single package
- Allows directly sensing near GND and V_{OUT} also goes to GND
- Compatible with all forms of logic
- Power drain suitable for battery operation

Features

- Internally frequency compensated for unity gain
- Large DC voltage gain 100 dB
- Wide bandwidth (unity gain) 1 MHz (temperature compensated)
- Wide power supply range:
  Single supply 3V to 32V
  or dual supplies ±1.5V to ±16V
- Very low supply current drain (700 µA) — essentially independent of supply voltage
- Low input biasing current 45 nA (temperature compensated)
- Low input offset voltage 2 mV
  and offset current: 5 nA
- Input common-mode voltage range includes ground
- Differential input voltage range equal to the power supply voltage
- Large output voltage swing 0V to V^+ – 1.5V

Connection Diagrams

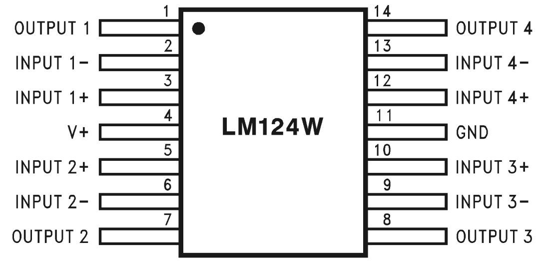
Dual-In-Line Package



Top View

Order Number LM124J, LM124AJ, LM124J/883 (Note 2)**, LM124AJ/883** (Note 1)**, LM224J, LM224AJ, LM324J, LM324M, LM324MX, LM324AM, LM324AMX, LM2902M, LM2902MX, LM324N, LM324AN, LM324MT, LM324MTX or LM2902N LM124AJRQML and LM124AJRQMLV**(Note 3)
See NS Package Number J14A, M14A or N14A

Connection Diagrams (Continued)



00929933

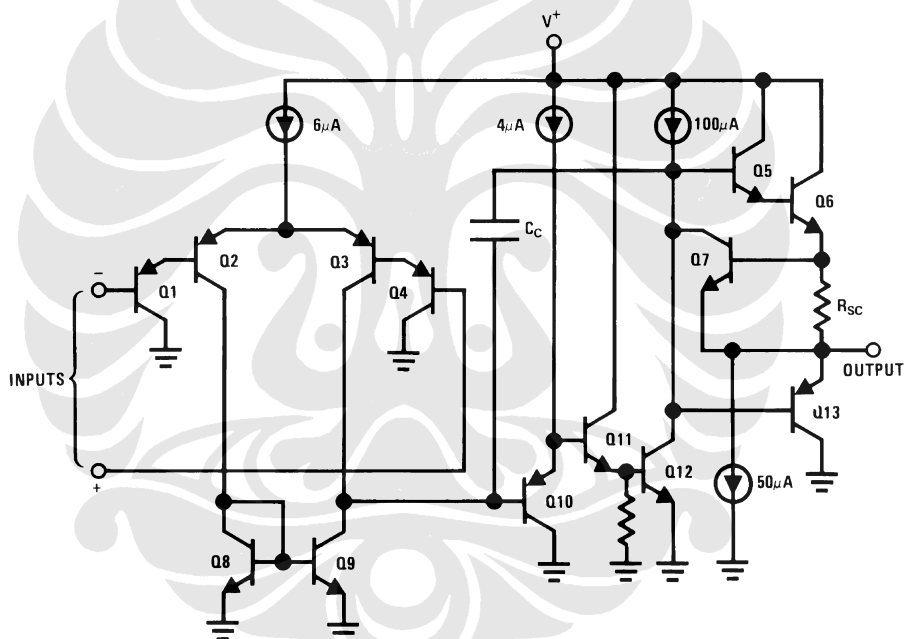
Order Number LM124AW/883, LM124AWG/883, LM124W/883 or LM124WG/883
LM124AWRQML and LM124AWRQMLV(Note 3)
See NS Package Number W14B
LM124AWGRQML and LM124AWGRQMLV(Note 3)
See NS Package Number WG14A

Note 1: LM124A available per JM38510/11006

Note 2: LM124 available per JM38510/11005

Note 3: See STD Mil DWG 5962R99504 for Radiation Tolerant Device

Schematic Diagram (Each Amplifier)



00929902

Absolute Maximum Ratings (Note 12)

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

	LM124/LM224/LM324 LM124A/LM224A/LM324A	LM2902
Supply Voltage, V^+	32V	26V
Differential Input Voltage	32V	26V
Input Voltage	−0.3V to +32V	−0.3V to +26V
Input Current		
(V_{IN} < −0.3V) (Note 6)	50 mA	50 mA
Power Dissipation (Note 4)		
Molded DIP	1130 mW	1130 mW
Cavity DIP	1260 mW	1260 mW
Small Outline Package	800 mW	800 mW
Output Short-Circuit to GND		
(One Amplifier) (Note 5)		
$V^+ \leq 15V$ and $T_A = 25°C$	Continuous	Continuous
Operating Temperature Range		−40˚C to +85˚C
LM324/LM324A	0˚C to +70˚C	
LM224/LM224A	−25˚C to +85˚C	
LM124/LM124A	−55˚C to +125˚C	
Storage Temperature Range	−65˚C to +150˚C	−65˚C to +150˚C
Lead Temperature (Soldering, 10 seconds)	260˚C	260˚C
Soldering Information		
Dual-In-Line Package		
Soldering (10 seconds)	260˚C	260˚C
Small Outline Package		
Vapor Phase (60 seconds)	215˚C	215˚C
Infrared (15 seconds)	220˚C	220˚C

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

ESD Tolerance (Note 13)	250V	250V

Electrical Characteristics

$V^+ = +5.0V$, (Note 7), unless otherwise stated

Parameter	Conditions	LM124A			LM224A			LM324A			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	(Note 8) $T_A = 25°C$		1	2		1	3		2	3	mV
Input Bias Current (Note 9)	$I_{IN(+)}$ or $I_{IN(-)}$, $V_{CM} = 0V$, $T_A = 25°C$		20	50		40	80		45	100	nA
Input Offset Current	$I_{IN(+)}$ or $I_{IN(-)}$, $V_{CM} = 0V$, $T_A = 25°C$		2	10		2	15		5	30	nA
Input Common-Mode Voltage Range (Note 10)	$V^+ = 30V$, (LM2902, $V^+ = 26V$), $T_A = 25°C$	0		$V^+-1.5$	0		$V^+-1.5$	0		$V^+-1.5$	V
Supply Current	Over Full Temperature Range $R_L = \infty$ On All Op Amps $V^+ = 30V$ (LM2902 $V^+ = 26V$) $V^+ = 5V$		 1.5 0.7	 3 1.2		 1.5 0.7	 3 1.2		 1.5 0.7	 3 1.2	mA
Large Signal Voltage Gain	$V^+ = 15V$, $R_L \geq 2k\Omega$, (V_O = 1V to 11V), $T_A = 25°C$	50	100		50	100		25	100		V/mV
Common-Mode	DC, V_{CM} = 0V to $V^+ - 1.5V$,	70	85		70	85		65	85		dB

Electrical Characteristics (Continued)

$V^+ = +5.0V$, (Note 7), unless otherwise stated

Parameter		Conditions		LM124A			LM224A			LM324A			Units
				Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Rejection Ratio		$T_A = 25°C$											
Power Supply Rejection Ratio		$V^+ = 5V$ to 30V (LM2902, $V^+ = 5V$ to 26V), $T_A = 25°C$		65	100		65	100		65	100		dB
Amplifier-to-Amplifier Coupling (Note 11)		f = 1 kHz to 20 kHz, $T_A = 25°C$ (Input Referred)			−120			−120			−120		dB
Output Current	Source	$V_{IN}^+ = 1V$, $V_{IN}^- = 0V$, $V^+ = 15V$, $V_O = 2V$, $T_A = 25°C$		20	40		20	40		20	40		mA
	Sink	$V_{IN}^- = 1V$, $V_{IN}^+ = 0V$, $V^+ = 15V$, $V_O = 2V$, $T_A = 25°C$		10	20		10	20		10	20		mA
		$V_{IN}^- = 1V$, $V_{IN}^+ = 0V$, $V^+ = 15V$, $V_O = 200$ mV, $T_A = 25°C$		12	50		12	50		12	50		μA
Short Circuit to Ground		(Note 5) $V^+ = 15V$, $T_A = 25°C$			40	60		40	60		40	60	mA
Input Offset Voltage		(Note 8)				4			4			5	mV
V_{OS} Drift		$R_S = 0\Omega$			7	20		7	20		7	30	μV/°C
Input Offset Current		$I_{IN(+)} - I_{IN(-)}$, $V_{CM} = 0V$				30			30			75	nA
I_{OS} Drift		$R_S = 0\Omega$			10	200		10	200		10	300	pA/°C
Input Bias Current		$I_{IN(+)}$ or $I_{IN(-)}$			40	100		40	100		40	200	nA
Input Common-Mode Voltage Range (Note 10)		$V^+ = +30V$ (LM2902, $V^+ = 26V$)		0		$V^+−2$	0		$V^+−2$	0		$V^+−2$	V
Large Signal Voltage Gain		$V^+ = +15V$ (V_OSwing = 1V to 11V) $R_L \geq 2$ kΩ		25			25			15			V/mV
Output Voltage Swing	V_{OH}	$V^+ = 30V$	$R_L = 2$ kΩ	26			26			26			V
		(LM2902, $V^+ = 26V$)	$R_L = 10$ kΩ	27	28		27	28		27	28		V
	V_{OL}	$V^+ = 5V$, $R_L = 10$ kΩ			5	20		5	20		5	20	mV
Output Current	Source	$V_O = 2V$	$V_{IN}^+ = +1V$, $V_{IN}^- = 0V$, $V^+ = 15V$	10	20		10	20		10	20		mA
	Sink		$V_{IN}^- = +1V$, $V_{IN}^+ = 0V$, $V^+ = 15V$	10	15		5	8		5	8		mA

Electrical Characteristics

$V^+ = +5.0V$, (Note 7), unless otherwise stated

Parameter	Conditions	LM124/LM224			LM324			LM2902			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	(Note 8) $T_A = 25°C$		2	5		2	7		2	7	mV
Input Bias Current (Note 9)	$I_{IN(+)}$ or $I_{IN(-)}$, $V_{CM} = 0V$, $T_A = 25°C$		45	150		45	250		45	250	nA
Input Offset Current	$I_{IN(+)}$ or $I_{IN(-)}$, $V_{CM} = 0V$, $T_A = 25°C$		3	30		5	50		5	50	nA
Input Common-Mode Voltage Range (Note 10)	$V^+ = 30V$, (LM2902, $V^+ = 26V$), $T_A = 25°C$	0		$V^+−1.5$	0		$V^+−1.5$	0		$V^+−1.5$	V

Electrical Characteristics (Continued)

$V^+ = +5.0V$, (Note 7), unless otherwise stated

Parameter		Conditions		LM124/LM224			LM324			LM2902			Units
				Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Supply Current		Over Full Temperature Range $R_L = \infty$ On All Op Amps											mA
		$V^+ = 30V$ (LM2902 $V^+ = 26V$)			1.5	3		1.5	3		1.5	3	
		$V^+ = 5V$			0.7	1.2		0.7	1.2		0.7	1.2	
Large Signal Voltage Gain		$V^+ = 15V$, $R_L \geq 2k\Omega$, (V_O = 1V to 11V), $T_A = 25^\circ C$		50	100		25	100		25	100		V/mV
Common-Mode Rejection Ratio		DC, $V_{CM} = 0V$ to $V^+ - 1.5V$, $T_A = 25^\circ C$		70	85		65	85		50	70		dB
Power Supply Rejection Ratio		$V^+ = 5V$ to 30V (LM2902, $V^+ = 5V$ to 26V), $T_A = 25^\circ C$		65	100		65	100		50	100		dB
Amplifier-to-Amplifier Coupling (Note 11)		f = 1 kHz to 20 kHz, $T_A = 25^\circ C$ (Input Referred)			−120			−120			−120		dB
Output Current	Source	$V_{IN}^+ = 1V$, $V_{IN}^- = 0V$, $V^+ = 15V$, $V_O = 2V$, $T_A = 25^\circ C$		20	40		20	40		20	40		mA
	Sink	$V_{IN}^- = 1V$, $V_{IN}^+ = 0V$, $V^+ = 15V$, $V_O = 2V$, $T_A = 25^\circ C$		10	20		10	20		10	20		mA
		$V_{IN}^- = 1V$, $V_{IN}^+ = 0V$, $V^+ = 15V$, $V_O = 200$ mV, $T_A = 25^\circ C$		12	50		12	50		12	50		μA
Short Circuit to Ground		(Note 5) $V^+ = 15V$, $T_A = 25^\circ C$			40	60		40	60		40	60	mA
Input Offset Voltage		(Note 8)				7			9			10	mV
V_{OS} Drift		$R_S = 0\Omega$			7			7			7		μV/°C
Input Offset Current		$I_{IN(+)} - I_{IN(-)}$, $V_{CM} = 0V$				100			150		45	200	nA
I_{OS} Drift		$R_S = 0\Omega$			10			10			10		pA/°C
Input Bias Current		$I_{IN(+)}$ or $I_{IN(-)}$			40	300		40	500		40	500	nA
Input Common-Mode Voltage Range (Note 10)		$V^+ = +30V$ (LM2902, $V^+ = 26V$)		0		V^+-2	0		V^+-2	0		V^+-2	V
Large Signal Voltage Gain		$V^+ = +15V$ (V_OSwing = 1V to 11V) $R_L \geq 2$ kΩ		25			15			15			V/mV
Output Voltage Swing	V_{OH}	$V^+ = 30V$	$R_L = 2$ kΩ	26			26			22			V
		(LM2902, $V^+ = 26V$)	$R_L = 10$ kΩ	27	28		27	28		23	24		
	V_{OL}	$V^+ = 5V$, $R_L = 10$ kΩ			5	20		5	20		5	100	mV
Output Current	Source	$V_O = 2V$	$V_{IN}^+ = +1V$, $V_{IN}^- = 0V$, $V^+ = 15V$	10	20		10	20		10	20		mA
	Sink		$V_{IN}^- = +1V$, $V_{IN}^+ = 0V$, $V^+ = 15V$	5	8		5	8		5	8		

Note 4: For operating at high temperatures, the LM324/LM324A/LM2902 must be derated based on a +125˚C maximum junction temperature and a thermal resistance of 88˚C/W which applies for the device soldered in a printed circuit board, operating in a still air ambient. The LM224/LM224A and LM124/LM124A can be derated based on a +150˚C maximum junction temperature. The dissipation is the total of all four amplifiers — use external resistors, where possible, to allow the amplifier to saturate of to reduce the power which is dissipated in the integrated circuit.

Note 5: Short circuits from the output to V^+ can cause excessive heating and eventual destruction. When considering short circuits to ground, the maximum output current is approximately 40 mA independent of the magnitude of V^+. At values of supply voltage in excess of +15V, continuous short-circuits can exceed the power dissipation ratings and cause eventual destruction. Destructive dissipation can result from simultaneous shorts on all amplifiers.

Note 6: This input current will only exist when the voltage at any of the input leads is driven negative. It is due to the collector-base junction of the input PNP transistors becoming forward biased and thereby acting as input diode clamps. In addition to this diode action, there is also lateral NPN parasitic transistor action

Electrical Characteristics (Continued)

on the IC chip. This transistor action can cause the output voltages of the op amps to go to the V^+voltage level (or to ground for a large overdrive) for the time duration that an input is driven negative. This is not destructive and normal output states will re-establish when the input voltage, which was negative, again returns to a value greater than −0.3V (at 25˚C).

Note 7: These specifications are limited to $-55^\circ C \le T_A \le +125^\circ C$ for the LM124/LM124A. With the LM224/LM224A, all temperature specifications are limited to $-25^\circ C \le T_A \le +85^\circ C$, the LM324/LM324A temperature specifications are limited to $0^\circ C \le T_A \le +70^\circ C$, and the LM2902 specifications are limited to $-40^\circ C \le T_A \le +85^\circ C$.

Note 8: $V_O \simeq 1.4V$, $R_S = 0\Omega$ with V^+ from 5V to 30V; and over the full input common-mode range (0V to V^+ − 1.5V) for LM2902, V^+ from 5V to 26V.

Note 9: The direction of the input current is out of the IC due to the PNP input stage. This current is essentially constant, independent of the state of the output so no loading change exists on the input lines.

Note 10: The input common-mode voltage of either input signal voltage should not be allowed to go negative by more than 0.3V (at 25˚C). The upper end of the common-mode voltage range is V^+ − 1.5V (at 25˚C), but either or both inputs can go to +32V without damage (+26V for LM2902), independent of the magnitude of V^+.

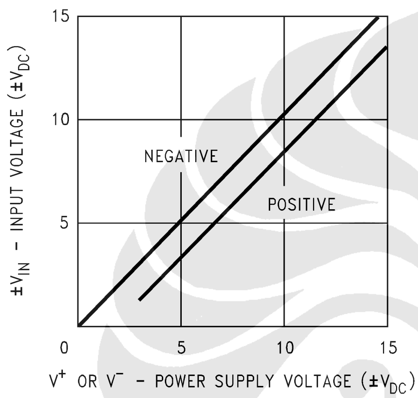
Note 11: Due to proximity of external components, insure that coupling is not originating via stray capacitance between these external parts. This typically can be detected as this type of capacitance increases at higher frequencies.

Note 12: Refer to RETS124AX for LM124A military specifications and refer to RETS124X for LM124 military specifications.

Note 13: Human body model, 1.5 kΩ in series with 100 pF.

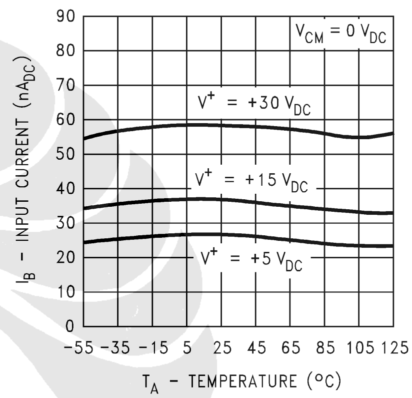
Typical Performance Characteristics

Input Voltage Range



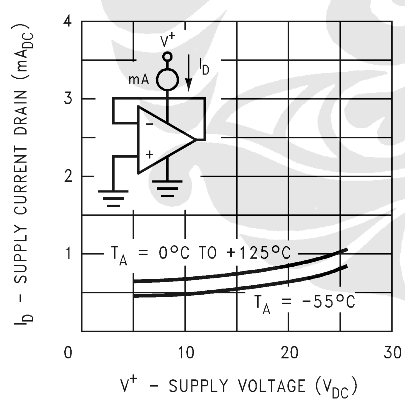
00929934

Input Current



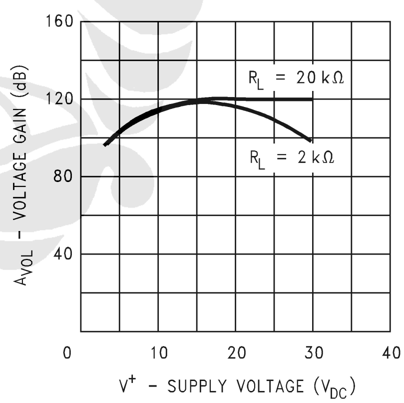
00929935

Supply Current



00929936

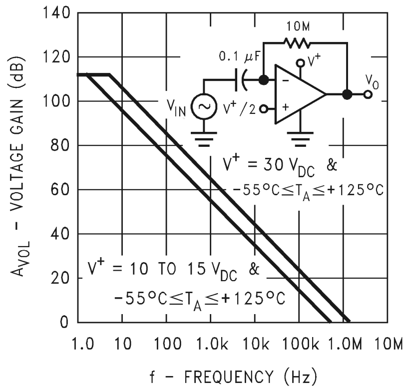
Voltage Gain



00929937

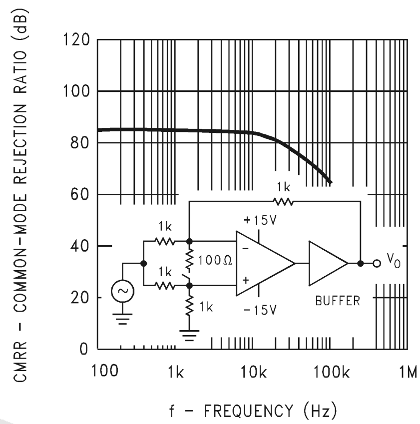
Typical Performance Characteristics (Continued)

Open Loop Frequency Response



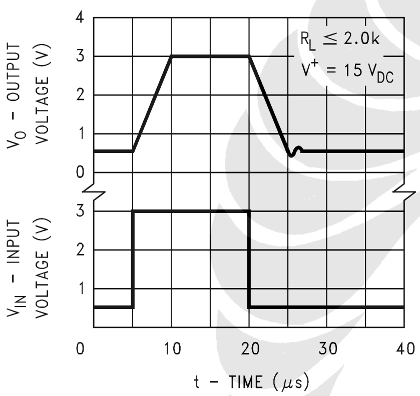
00929938

Common Mode Rejection Ratio



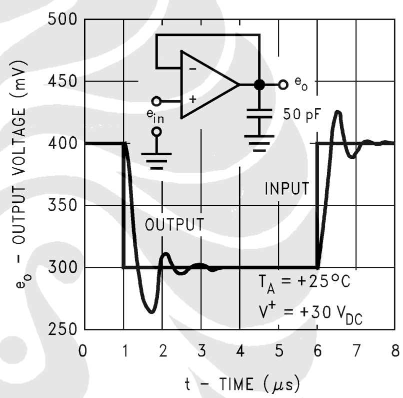
00929939

Voltage Follower Pulse Response



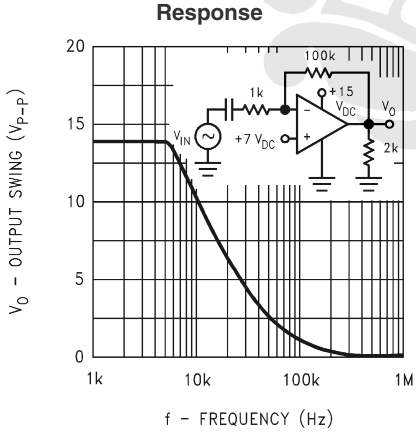
00929940

Voltage Follower Pulse Response (Small Signal)



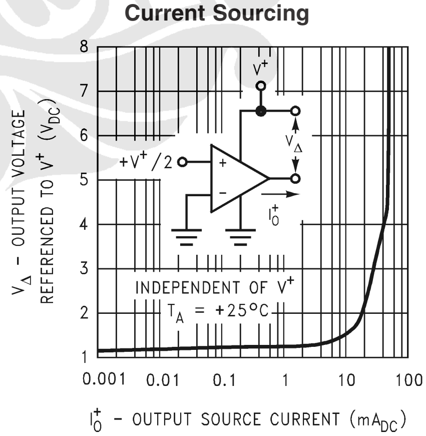
00929941

Large Signal Frequency Response



00929942

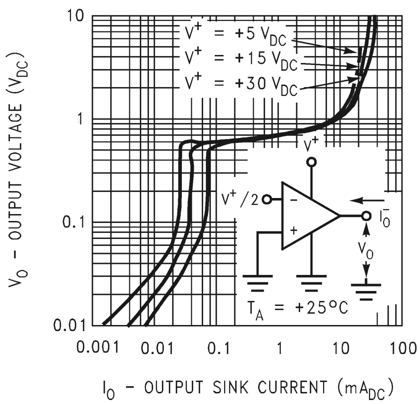
Output Characteristics Current Sourcing



00929943

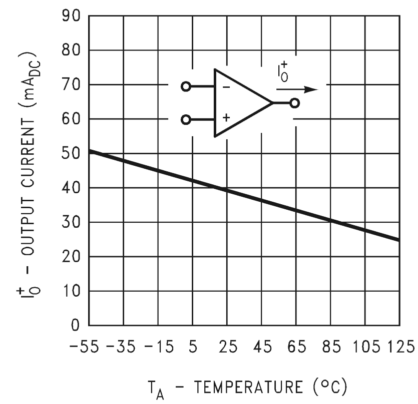
Typical Performance Characteristics (Continued)

Output Characteristics Current Sinking



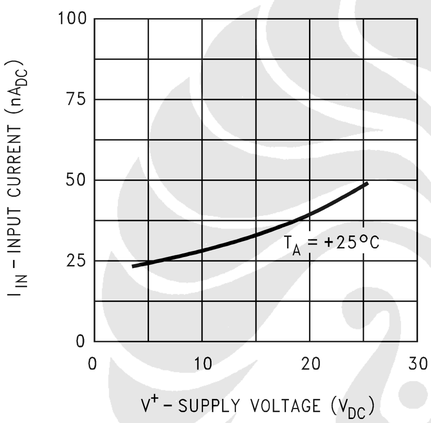
00929944

Current Limiting



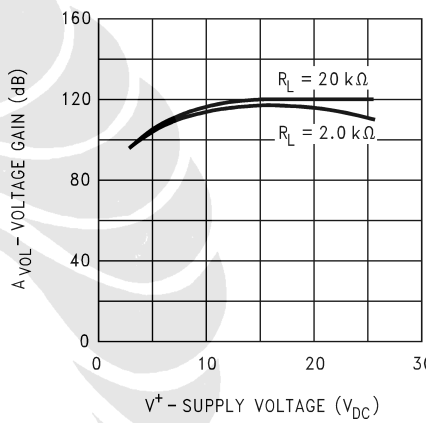
00929945

Input Current (LM2902 only)



00929946

Voltage Gain (LM2902 only)



00929947

Application Hints

The LM124 series are op amps which operate with only a single power supply voltage, have true-differential inputs, and remain in the linear mode with an input common-mode voltage of 0 V_{DC}. These amplifiers operate over a wide range of power supply voltage with little change in performance characteristics. At 25˚C amplifier operation is possible down to a minimum supply voltage of 2.3 V_{DC}.

The pinouts of the package have been designed to simplify PC board layouts. Inverting inputs are adjacent to outputs for all of the amplifiers and the outputs have also been placed at the corners of the package (pins 1, 7, 8, and 14).

Precautions should be taken to insure that the power supply for the integrated circuit never becomes reversed in polarity or that the unit is not inadvertently installed backwards in a test socket as an unlimited current surge through the resulting forward diode within the IC could cause fusing of the internal conductors and result in a destroyed unit.

Large differential input voltages can be easily accommodated and, as input differential voltage protection diodes are not needed, no large input currents result from large differential input voltages. The differential input voltage may be larger than V^+ without damaging the device. Protection should be provided to prevent the input voltages from going negative more than –0.3 V_{DC} (at 25˚C). An input clamp diode with a resistor to the IC input terminal can be used.

To reduce the power supply drain, the amplifiers have a class A output stage for small signal levels which converts to class B in a large signal mode. This allows the amplifiers to both source and sink large output currents. Therefore both NPN and PNP external current boost transistors can be used to extend the power capability of the basic amplifiers. The output voltage needs to raise approximately 1 diode drop above ground to bias the on-chip vertical PNP transistor for output current sinking applications.

For ac applications, where the load is capacitively coupled to the output of the amplifier, a resistor should be used, from the output of the amplifier to ground to increase the class A bias current and prevent crossover distortion.

Where the load is directly coupled, as in dc applications, there is no crossover distortion.

Capacitive loads which are applied directly to the output of the amplifier reduce the loop stability margin. Values of 50 pF can be accommodated using the worst-case non-inverting unity gain connection. Large closed loop gains or resistive isolation should be used if larger load capacitance must be driven by the amplifier.

Application Hints (Continued)

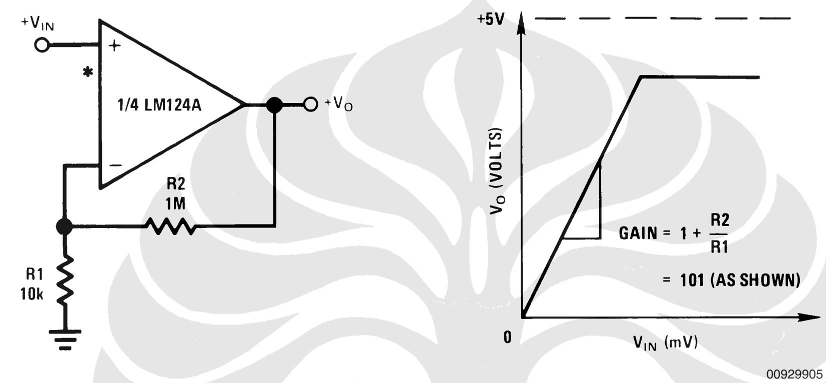
The bias network of the LM124 establishes a drain current which is independent of the magnitude of the power supply voltage over the range of from 3 V_{DC} to 30 V_{DC}.

Output short circuits either to ground or to the positive power supply should be of short time duration. Units can be destroyed, not as a result of the short circuit current causing metal fusing, but rather due to the large increase in IC chip dissipation which will cause eventual failure due to excessive junction temperatures. Putting direct short-circuits on more than one amplifier at a time will increase the total IC power dissipation to destructive levels, if not properly protected with external dissipation limiting resistors in series with the output leads of the amplifiers. The larger value of output source current which is available at 25˚C provides a larger output current capability at elevated temperatures (see typical performance characteristics) than a standard IC op amp.

The circuits presented in the section on typical applications emphasize operation on only a single power supply voltage. If complementary power supplies are available, all of the standard op amp circuits can be used. In general, introducing a pseudo-ground (a bias voltage reference of $V^+/2$) will allow operation above and below this value in single power supply systems. Many application circuits are shown which take advantage of the wide input common-mode voltage range which includes ground. In most cases, input biasing is not required and input voltages which range to ground can easily be accommodated.

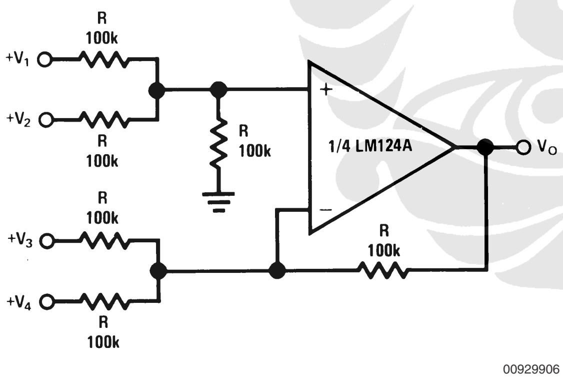
Typical Single-Supply Applications (V^+ = 5.0 V_{DC})

Non-Inverting DC Gain (0V Input = 0V Output)



*R not needed due to temperature independent I_{IN}

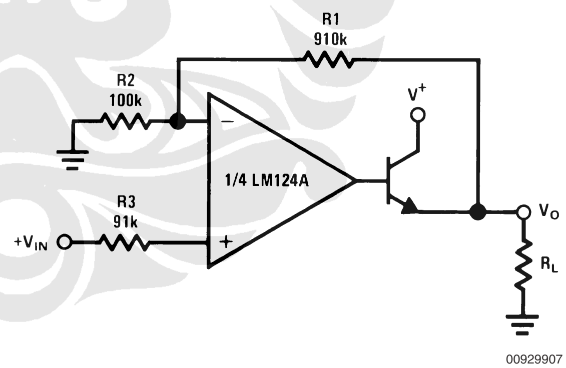
DC Summing Amplifier ($V_{IN'S}$ ≥ 0 V_{DC} and V_O ≥ V_{DC})



Where: $V_0 = V_1 + V_2 - V_3 - V_4$

$(V_1 + V_2) \geq (V_3 + V_4)$ to keep $V_O > 0$ V_{DC}

Power Amplifier

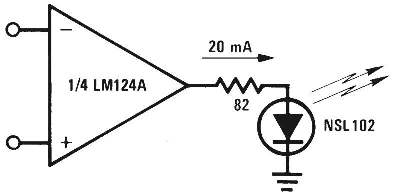


V_0 = 0 V_{DC} for V_{IN} = 0 V_{DC}

A_V = 10

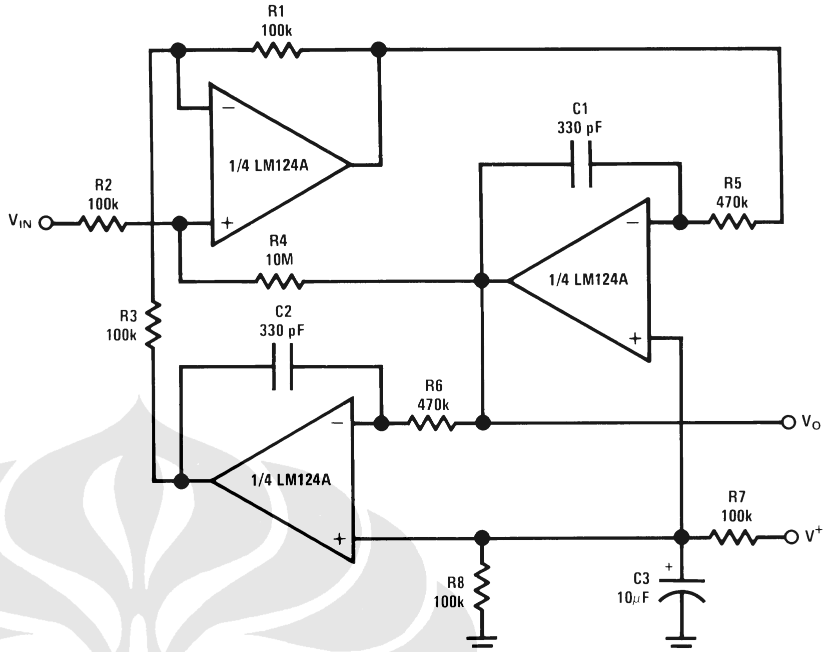
Typical Single-Supply Applications (V^+ = 5.0 V_{DC}) (Continued)

LED Driver



00929908

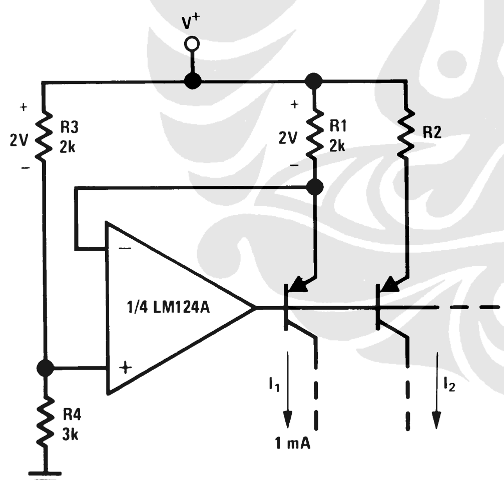
"BI-QUAD" RC Active Bandpass Filter



00929909

f_o = 1 kHz
Q = 50
A_V = 100 (40 dB)

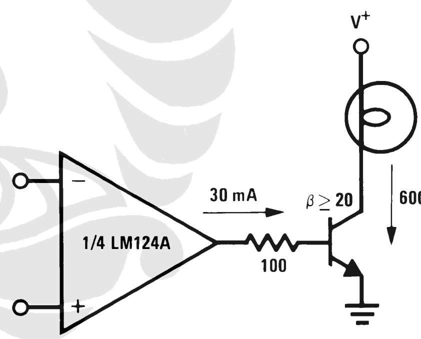
Fixed Current Sources



00929910

$$I_2 = \left(\frac{R1}{R2}\right) I_1$$

Lamp Driver

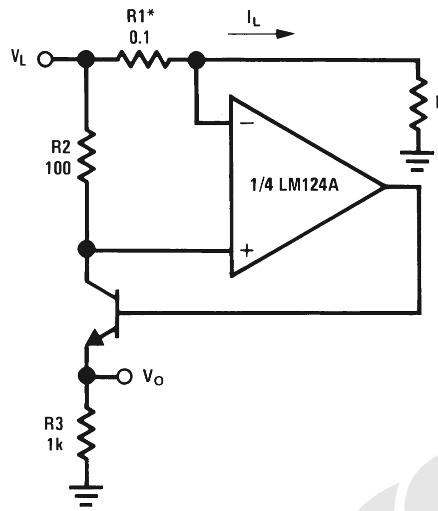


00929911

Typical Single-Supply Applications

($V^+ = 5.0\ V_{DC}$) (Continued)

Current Monitor



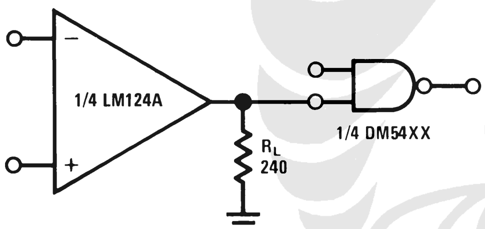
00929912

$$V_O = \frac{1V(I_L)}{1A}$$

$$V_L \leq V^+ - 2V$$

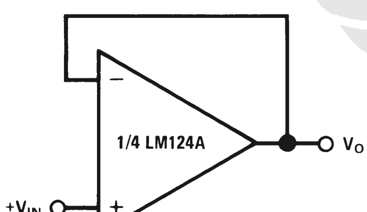
*(Increase R1 for I_L small)

Driving TTL



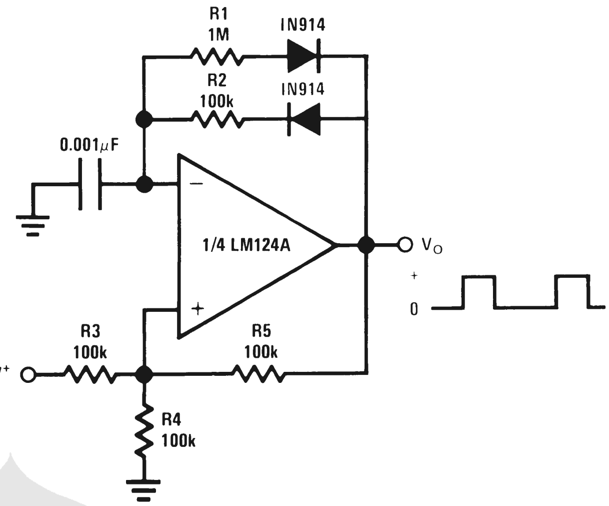
00929913

Voltage Follower



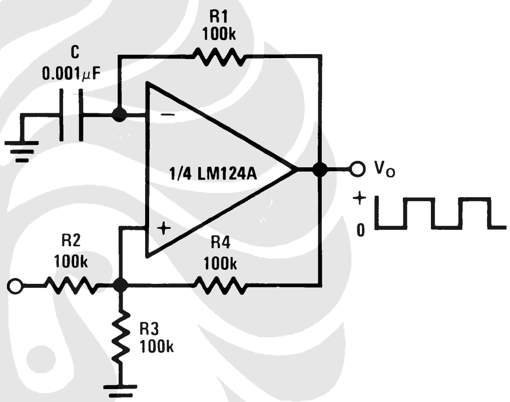
00929914

Pulse Generator



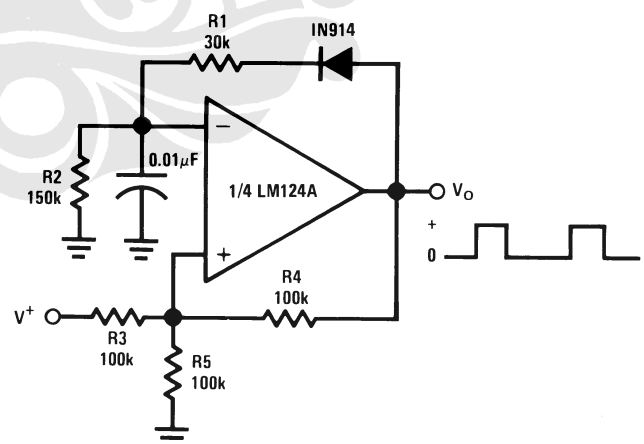
00929915

Squarewave Oscillator



00929916

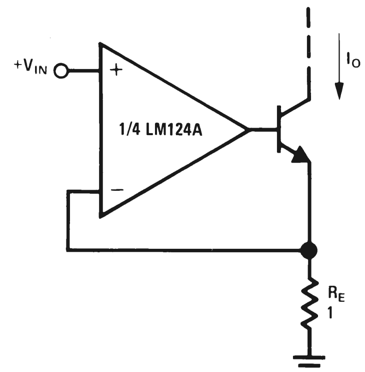
Pulse Generator



00929917

Typical Single-Supply Applications (V^+ = 5.0 V_{DC}) (Continued)

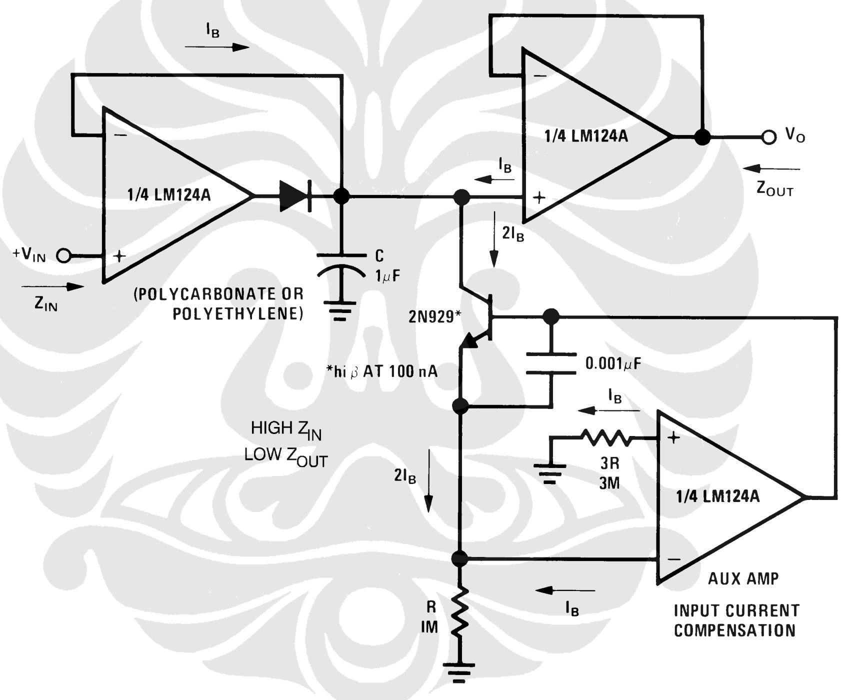
High Compliance Current Sink



00929918

I_O = 1 amp/volt V_{IN}
(Increase R_E for I_o small)

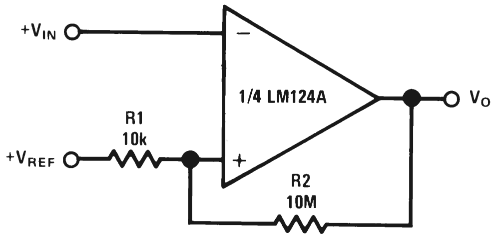
Low Drift Peak Detector



00929919

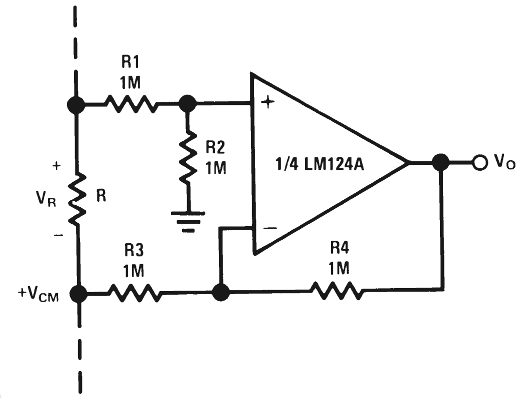
Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$) (Continued)

Comparator with Hysteresis



00929920

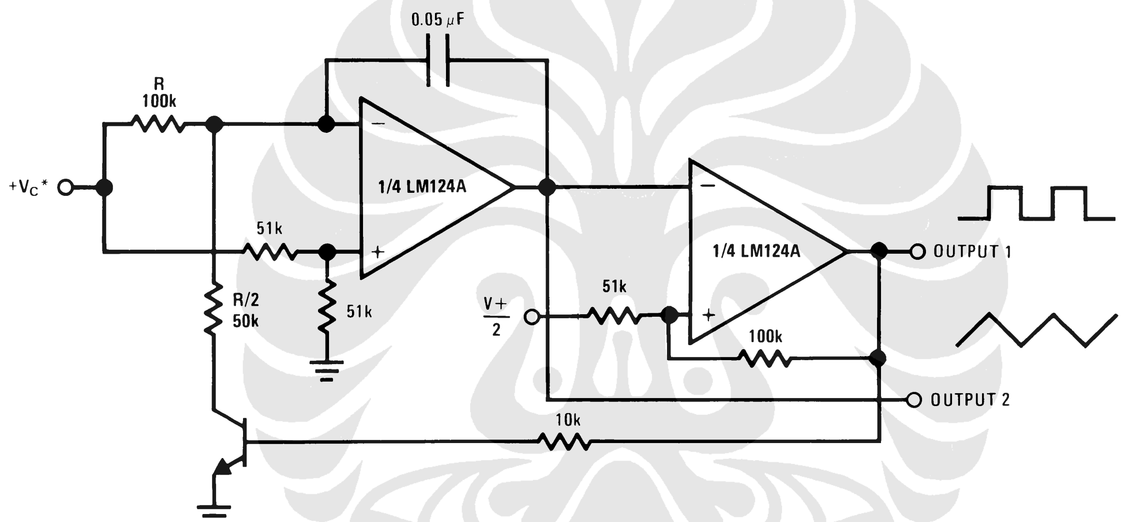
Ground Referencing a Differential Input Signal



00929921

$V_O = V_R$

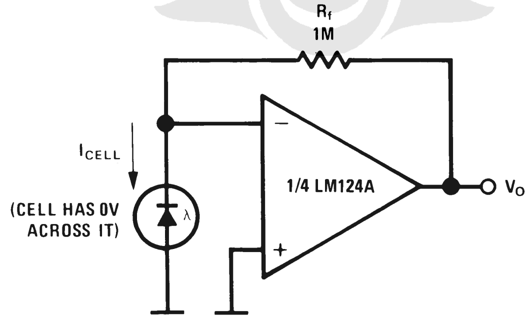
Voltage Controlled Oscillator Circuit



00929922

*Wide control voltage range: $0\ V_{DC} \le V_C \le 2\ (V^+ - 1.5\ V_{DC})$

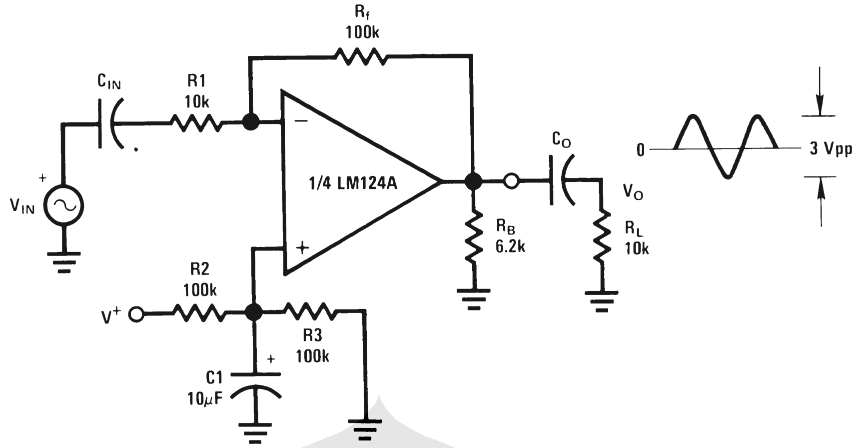
Photo Voltaic-Cell Amplifier



00929923

Typical Single-Supply Applications (V^+ = 5.0 V_{DC}) (Continued)

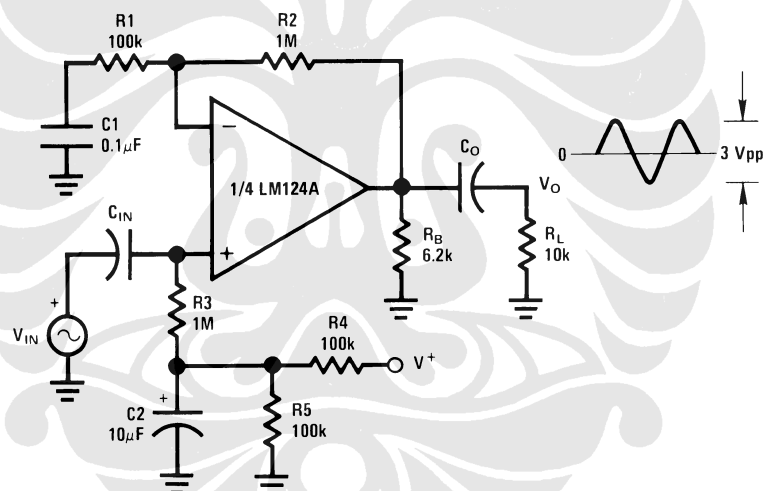
AC Coupled Inverting Amplifier



00929924

$$A_V = \frac{R_f}{R1} \text{ (As shown, } A_V = 10\text{)}$$

AC Coupled Non-Inverting Amplifier



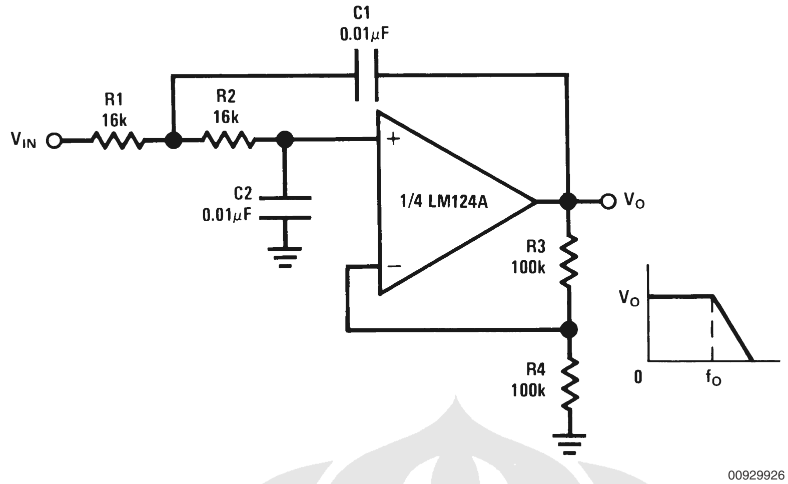
00929925

$$A_V = 1 + \frac{R2}{R1}$$

A_V = 11 (As shown)

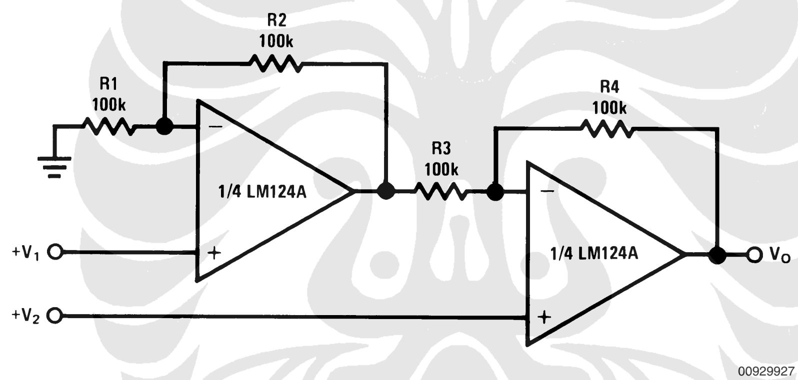
Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$) (Continued)

DC Coupled Low-Pass RC Active Filter



$f_O = 1$ kHz
Q = 1
$A_V = 2$

High Input Z, DC Differential Amplifier



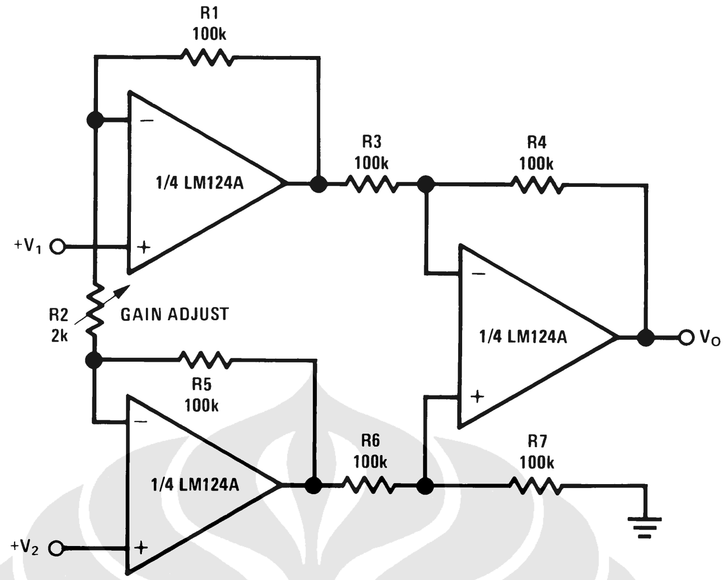
For $\frac{R1}{R2} = \frac{R4}{R3}$ (CMRR depends on this resistor ratio match)

$V_O = 1 + \frac{R4}{R3} (V_2 - V_1)$

As shown: $V_O = 2(V_2 - V_1)$

Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$) (Continued)

High Input Z Adjustable-Gain DC Instrumentation Amplifier



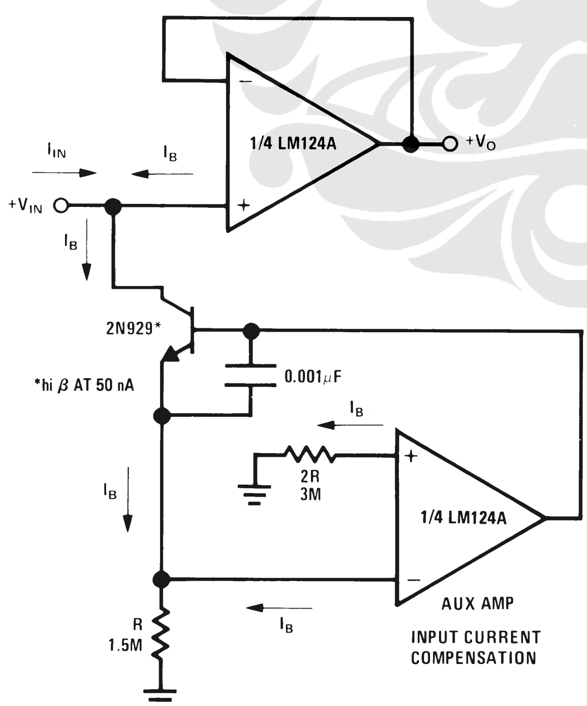
00929928

If R1 = R5 & R3 = R4 = R6 = R7 (CMRR depends on match)

$$V_O = 1 + \frac{2R1}{R2}(V_2 - V_1)$$

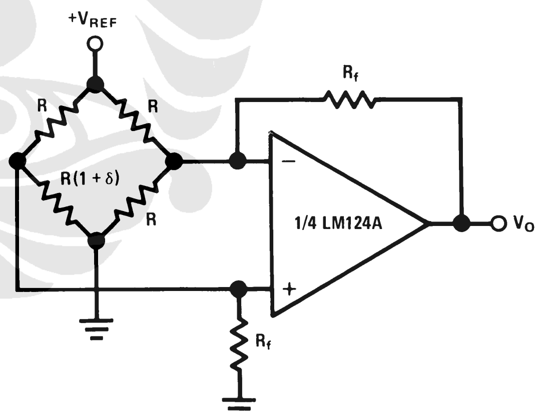
As shown $V_O = 101\ (V_2 - V_1)$

Using Symmetrical Amplifiers to Reduce Input Current (General Concept)



00929929

Bridge Current Amplifier



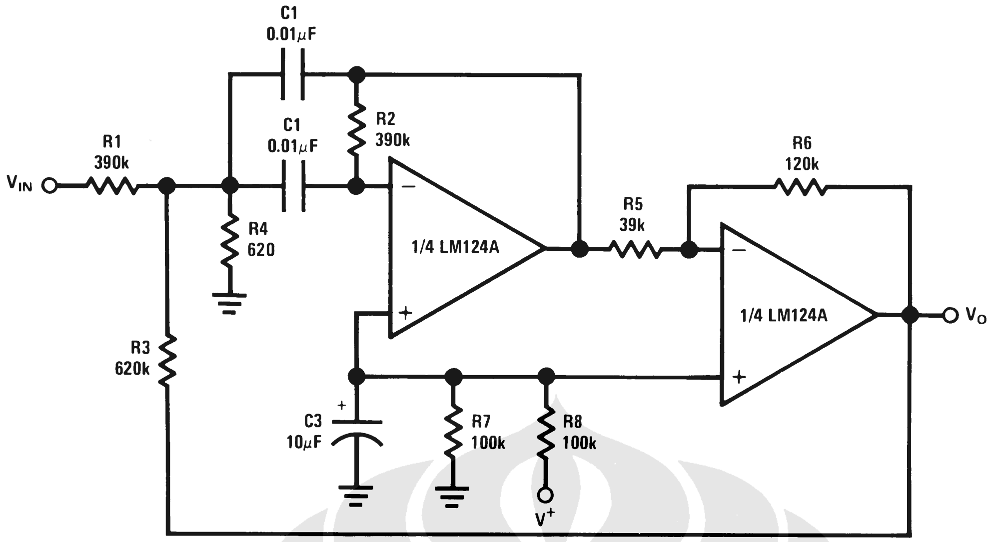
00929930

For δ << 1 and $R_f >> R$

$$V_O \cong V_{REF}\left(\frac{\delta}{2}\right)\frac{R_f}{R}$$

Typical Single-Supply Applications ($V^{+} = 5.0\ V_{DC}$) (Continued)

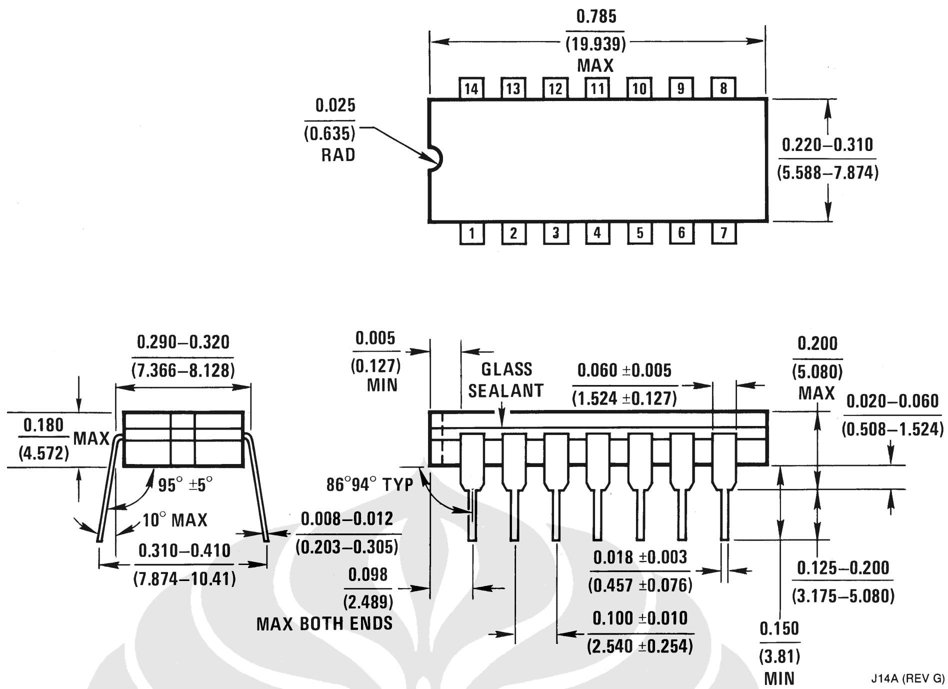
Bandpass Active Filter



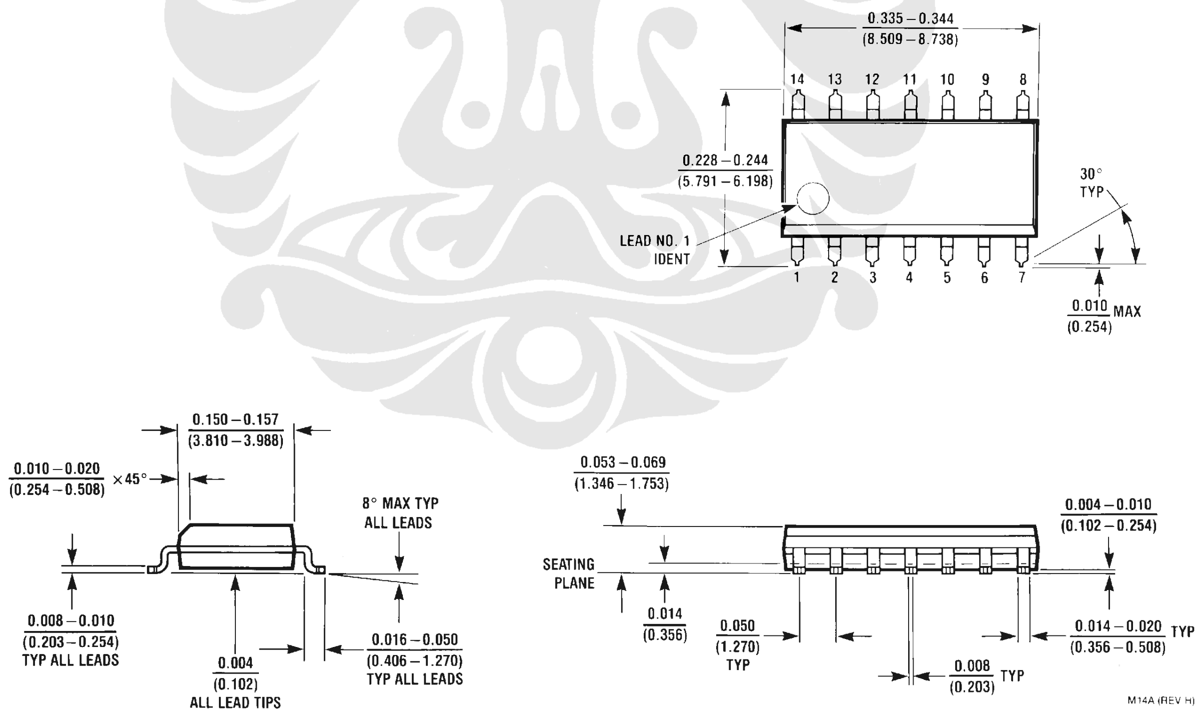
00929931

f_O = 1 kHz
Q = 25

Physical Dimensions inches (millimeters) unless otherwise noted

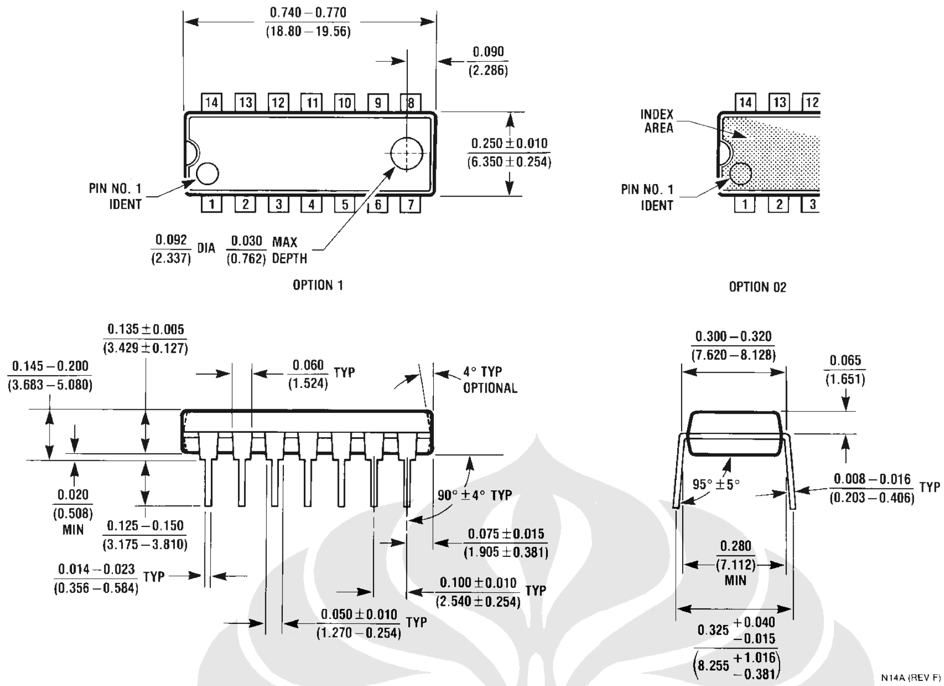


Ceramic Dual-In-Line Package (J)
Order Number JL124ABCA, JL124BCA, JL124ASCA, JL124SCA, LM124J, LM124AJ, LM124AJ/883, LM124J/883, LM224J, LM224AJ or LM324J
NS Package Number J14A

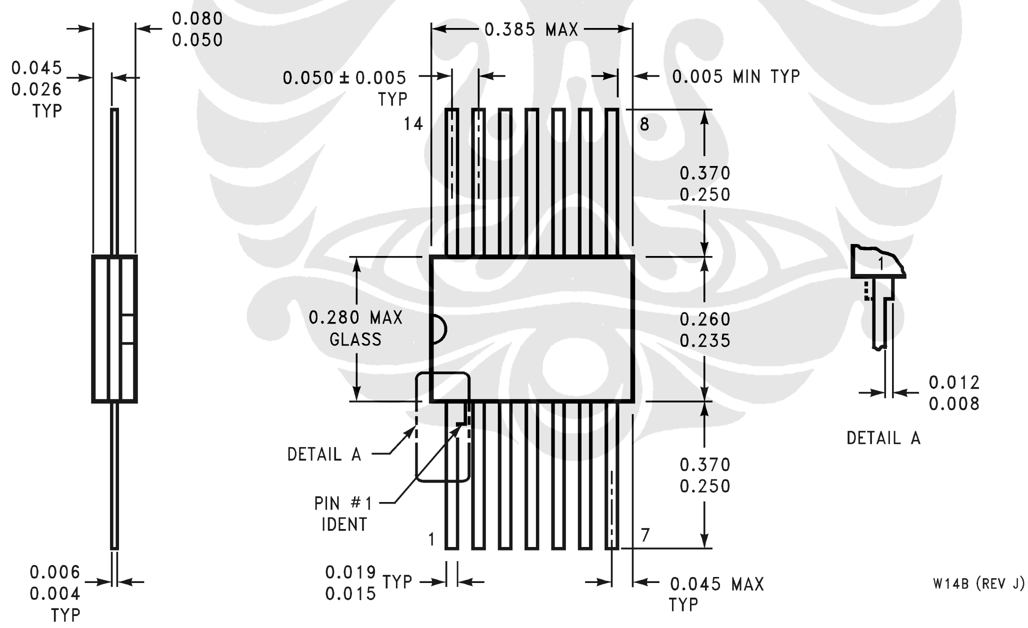


MX S.O. Package (M)
Order Number LM324M, LM324MX, LM324AM, LM324AMX, LM2902M or LM2902MX
NS Package Number M14A

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

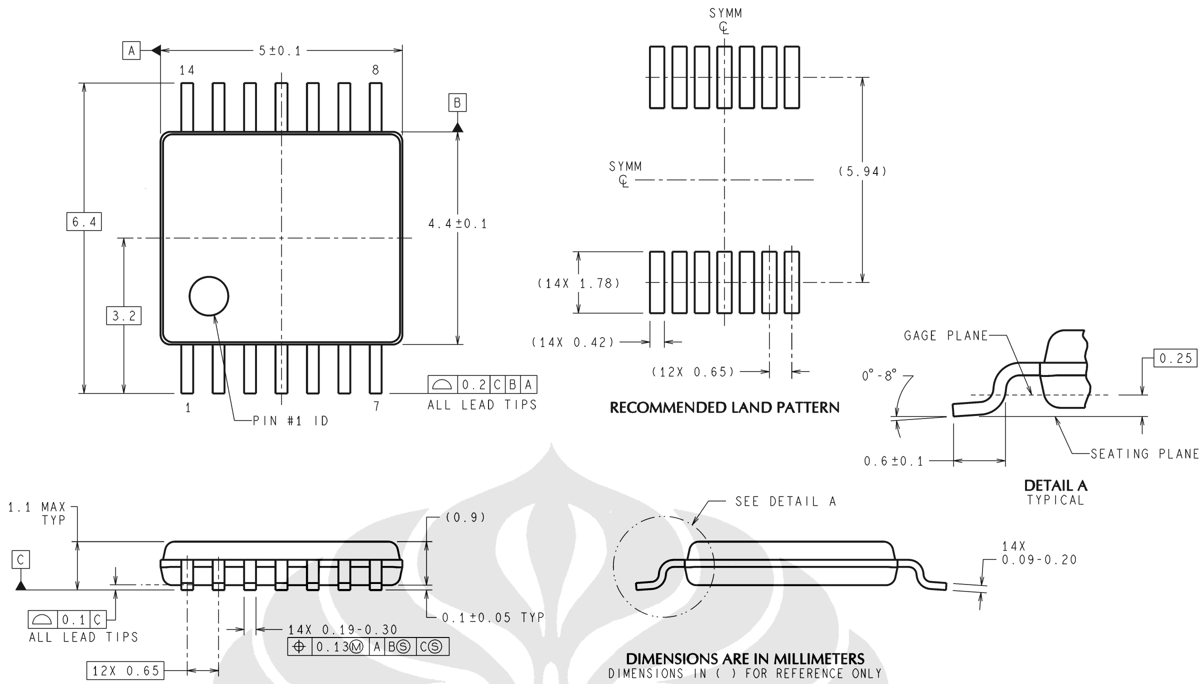


Molded Dual-In-Line Package (N)
Order Number LM324N, LM324AN or LM2902N
NS Package Number N14A



Ceramic Flatpak Package
Order Number JL124ABDA, JL124ABZA, JL124ASDA, JL124BDA, JL124BZA, JL124SDA, LM124AW/883, LM124AWG/883, LM124W/883 or LM124WG/883
NS Package Number W14B

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



MTC14 (Rev D)

14-Pin TSSOP
Order NumberLM324MT or LM324MTX
NS Package Number MTC14

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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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KBBC SERIES

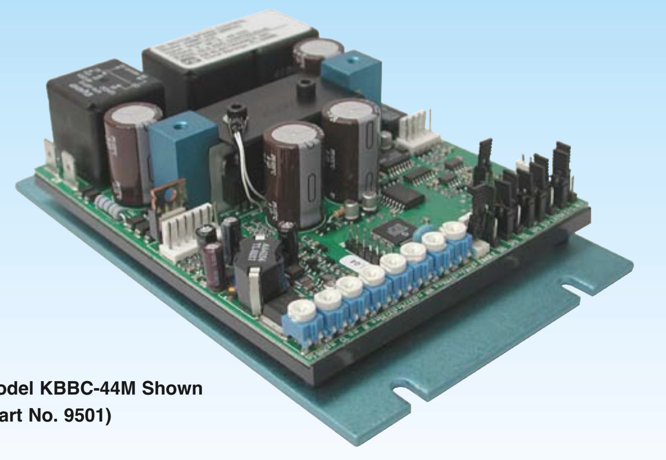
MICROPROCESSOR CONTROLLED BATTERY POWERED DC/DC

Variable Speed Motor Control

for 12, 24, 36 and 48 Volt PM and Series Wound DC Motors thru 2HP Continuous Duty and 4HP Peak Duty

TYPICAL APPLICATIONS

• Scooters • Personnel Carriers • Carts • Electric Boats • Portable Pumps • Lifts • Floor Polishers



Model KBBC-44M Shown (Part No. 9501)

STANDARD FEATURES

- **High Frequency PWM Operation:** Reduces motor noise and increases efficiency.
- **Controlled Acceleration and Deceleration:** Provides timed acceleration to set speed and deceleration to zero speed.
- **Diagnostic LEDs:** Provide indication of power on (PWR ON) and control status (STATUS).
- **Built-In Reversing Contactor:** Provides forward/reverse operation with a low power reversing switch or with a center-off throttle potentiometer (wigwag).
- **Run Relay:** Used to turn on or off equipment or signal a warning if a fault has occurred.
- **Brake Driver Circuit:** Powers an optional electromechanical brake (current regulated and short circuit protected).
- **Key Switch Operation with Built-In Battery Power Contactor:** Allows the use of a low power switch to turn control on and off.
- **Inhibit Circuit:** Allows control to be turned off electronically with a separate low power switch.
- **Latching Circuit:** Allows momentary switches to start, stop, and reverse the control.
- **Limit Switch Circuit** (Stop Forward and Stop Reverse)**:** Allows limit switches to be used to immediately stop the control in forward or reverse directions.
- **Single-Ended or Wigwag Potentiometer Control:** Allows the Main Speed Potentiometer to be used as single-ended (zero speed is at 0% rotation) or wigwag (zero speed is at 50% rotation).

PROTECTIVE FEATURES

- **Electronic Current Limit:** Protects the motor and control against overload.
- **Polarity Protected:** Prevents control damage if the battery is wired incorrectly.
- **Short Circuit Protected:** Protects main power transistor from failure due to a short at the motor.
- **Overtemperature Protection:** Reduces control output as the transistors reach maximum operating temperature.
- **Overvoltage Protection:** Will turn off the control if the battery voltage exceeds 125% of nominal.
- **Undervoltage Protection:** Will turn off the control if battery voltage reduces below 65% of nominal.

SAFETY FEATURES

- **Potentiometer Fault Circuit:** Turns the control off if a short, open, or ground occurs at the potentiometer.
- **High Pedal Disable Function:** Prevents control startup until the potentiometer returns to zero.

DESCRIPTION

The KBBC series of battery powered variable speed controls are designed for 12, 24, 36, and 48 Volt PM and Series Wound DC motors. Microcontroller design provides superior performance and ease of tailoring to specific applications. Operating in a regenerative mode, precise and efficient control is obtained using state-of-the-art MOSFET technology. The KBBC operates at a switching frequency of 16 kHz, which provides high motor efficiency and quiet operation.

The KBBC contains many standard features such as current limit, short circuit protection, speed potentiometer fault detector, overtemperature sensing, and undervoltage/overvoltage protection. A variety of trimpots are provided, which can be used to tailor the control to exact specifications. The control also contains LEDs that indicate “power on” and “status.” A DC power contactor allows a low power switch to turn the control on and off. Reversing contactors provide arcless forward, stop, and reverse operation. In addition, a brake driver circuit is used to power an optional electromagnetic brake.

The KBBC can be controlled in several ways, such as single-ended or wigwag speed potentiometer and 0 - 5 Volts DC signal following. The controls contain a built-in heat sink that also serves as a mounting base.

TRIMPOT ADJUSTMENTS

- **Timed Brake Delay (T-BRK):** Sets the delay time before the brake is engaged.
- **Current Limit (CL):** Sets the current limit (overload), which limits the maximum current to the motor.
- **IR Compensation (IR):** Sets the amount of compensating voltage required to keep the motor speed constant under changing loads.
- **Deceleration (DECEL):** Sets the amount of time for the motor to decelerate from the set speed to zero speed.
- **Acceleration (ACCEL):** Sets the amount of time for the motor to accelerate from zero speed to the set speed.
- **Minimum Speed (MIN):** Sets the minimum motor speed.
- **Reverse Maximum Speed (RMAX):** Sets the maximum motor speed in the reverse direction (a % of FMAX setting).
- **Forward Maximum Speed (FMAX):** Sets the maximum motor speed in the forward direction.

PENTA KB POWER™

A Complete Line of Motor Drives

GENERAL PERFORMANCE SPECIFICATIONS

Parameter	Specification	Factory Setting
Input Voltage Range (% Nominal)	75 – 125	100
Intermittent Duty Operation (Minutes)	2	—
Peak Duty Operation (Seconds)	7	—
Overvoltage Shutdown (% Nominal Input Voltage)	125	—
Undervoltage Warning (% Nominal Input Voltage, ± 10%)	85	—
Undervoltage Shutdown (% Nominal Input Voltage)	65	—
Nominal Carrier Frequency (kHz)	16	—
Electromagnetic Brake Delay Trimpot (T-BRK) Range (Seconds)	0.2 – 2.5	1
CL Trimpot (CL) Range (% Range Setting)	0 – 200	150
IR Compensation Trimpot (IR) Range (% Nominal Battery Voltage)	0 – 25	4
Acceleration Trimpot (ACCEL) Range (% Base Speed)	0.1 – 15	2
Deceleration Trimpot (DECEL) Range (% Base Speed)	0.1 – 15	2
Minimum Trimpot (MIN) Range (% Base Speed)	0 – 30	0
Forward Maximum Speed Trimpot (FMAX) Range (% Base Speed)*	60 – 100	100
Reverse Maximum Speed Trimpot (RMAX) Range (% Forward Maximum Speed)	50 – 100	100
Electromagnetic Brake Current Rating (Amps DC)	1	—
Heat Sink Overtemperature Protection Point (°C)	100	—
Deadband in Wigwag Throttle Mode (Volts DC)	± 0.3	—
Wigwag Throttle Signal Input Voltage for Maximum Forward (Volts DC)	2.5 – 5.0	5
Wigwag Throttle Signal Input Voltage for Neutral (Volts DC)	1.2 – 2.5	2.5
Wigwag Throttle Signal Input Voltage for Maximum Reverse (Volts DC)	0	0
Single Ended Throttle Signal Range for Full Speed Forward or Reverse (Volts DC)	0 – 2.5 to 5.0	0 – 5
Timed Current Limit (TCL) Trip Time (Seconds)	7	—
Run Relay Output Contact Rating (Amps at 30 Volts DC, Amps at 125 Volts AC)	1, 0.5	—
Auxiliary Power Connector (P2) Rating (Maximum Amps DC)	10	—
Operating Temperature Range (°C)	0 – 45	—

*FMAX trimpot is also used as an input/output gain potentiometer.

ELECTRICAL RATINGS

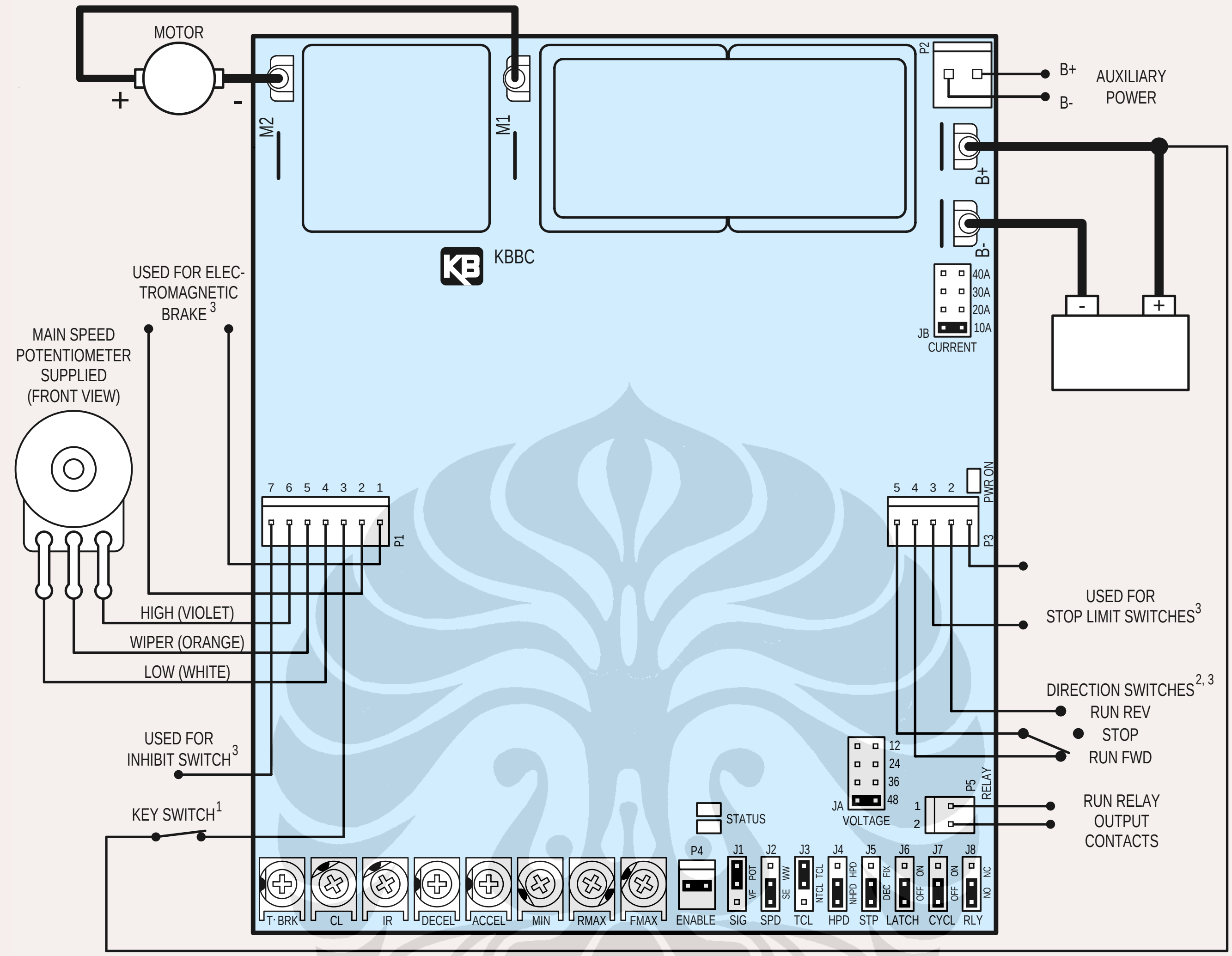
Model No.	Part No.	Nominal Battery Voltage (Volts DC)	Nominal Motor Voltage (Volts DC)	Continuous Duty		Intermittent Duty (2 Minutes)		Peak Duty (7 Seconds)	
				Maximum HP	Amps DC	Maximum HP	Amps DC	Maximum HP	Amps DC
KBBC-24M	9500	12	0 – 12	1/2	40	3/4	60	1	80
		24	0 – 24	1	40	1½	60	2	80
KBBC-44M	9501	12	0 – 12	1/2	40	3/4	60	1	80
		24	0 – 24	1	40	1½	60	2	80
		36	0 – 36	1½	40	2	60	3	80
		48	0 – 48	2	40	3	60	4	80

Note: Custom units are available with various voltages and currents with or without DC Power Contactor or Reversing Contactor.

JUMPER SELECTABLE FEATURES

- **JA - Battery Voltage (VOLTAGE - 12/24/36/48):** Selects nominal battery voltage.
- **JB - Motor Current (CURRENT - 10A/20A/30A/40A):** Selects nominal motor current.
- **J1 - Signal Type (SIG - VF/POT):** Selects voltage following or potentiometer operation.
- **J2 - Speed Potentiometer Mode (SPD - SE/WW):** Selects single-ended or wigwag speed control.
- **J3 - Current Limit Mode (TCL - NTCL/TCL):** Selects non-timed current limit or timed current limit.
- **J4 - High Pedal Mode (HPD - NHPD/HPD):** Selects non-high pedal disable or high pedal disable.
- **J5 - Deceleration Mode (STP - DEC/FIX):** Selects adjustable or fixed (0.1 second) deceleration when a stop command is given.
- **J6 - Direction Switch Type (LATCH - OFF/ON):** Selects maintained or momentary direction commands.
- **J7 - Cycling Mode (CYCL - OFF/ON):** Selects cycling of relay which is used to brake the motor.
- **J8 - Relay Output Contacts (RLY - NO/NC):** Selects normally open or normally closed Run Relay contacts.

CONTROL LAYOUT & CONNECTION DIAGRAM

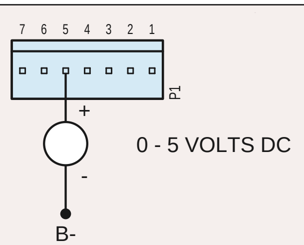


Notes: 1. *If Key Switch is not used, a connection must be made between the red wire of Connector P1 and quick-connect Terminal B+ for the control to operate.*

2. RUN FWD and RUN REV Direction Switches are not used in wigwag operation.

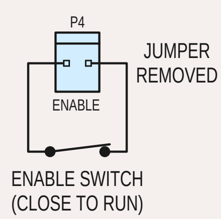
3. Customer supplied.

VOLTAGE FOLLOWING CONNECTION

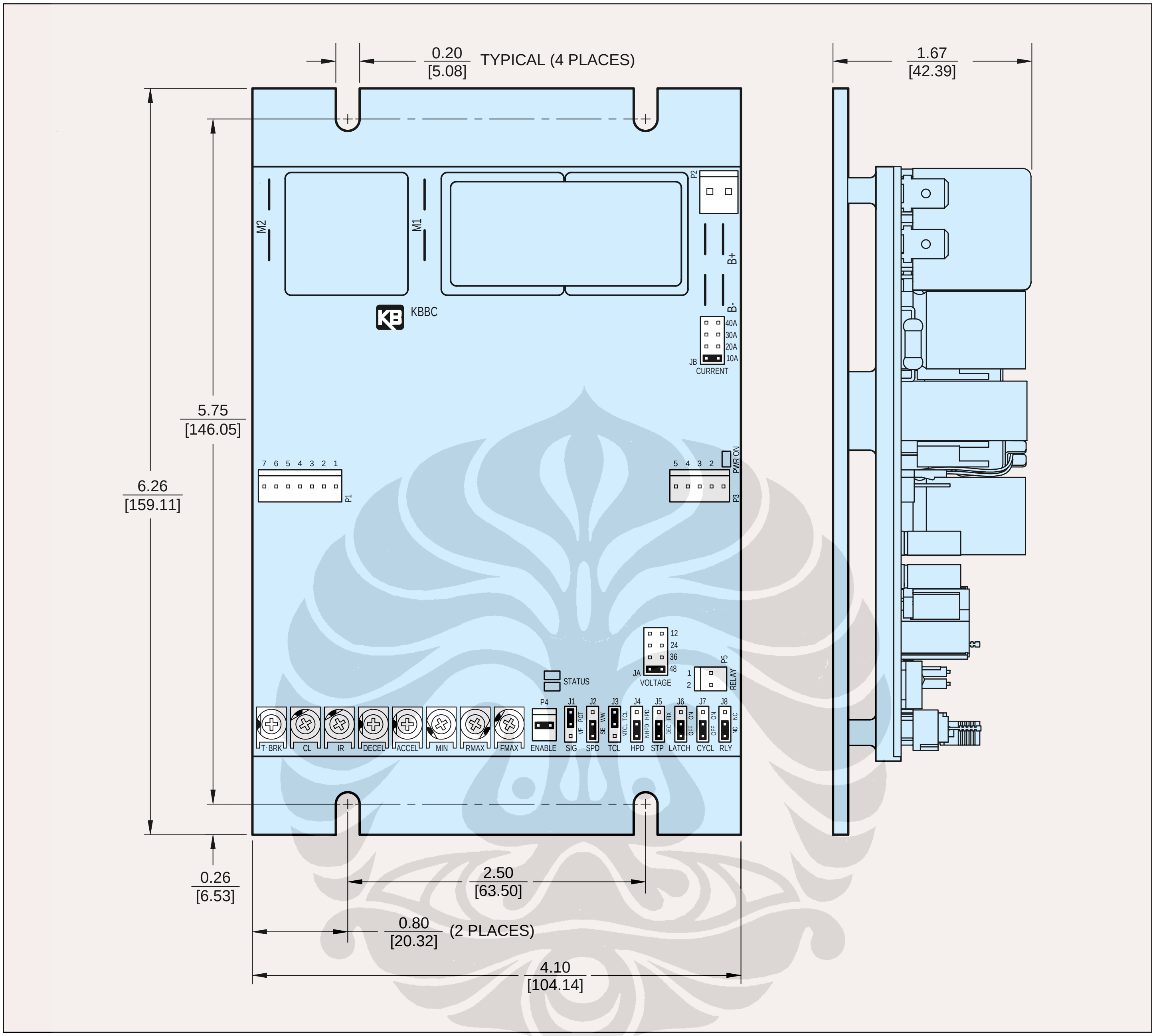


Note: Set Jumper J1 to the "VF" position

ENABLE SWITCH CONNECTION



MECHANICAL SPECIFICATIONS (Inches / [mm])



GREEN AND RED STATUS LEDs

Control Status	Green LED	Red LED	Flash Rate*
Run	On	Off	Slow
Stop	On	Off	Quick
Curent Limit (Warning)	Off	On	Steady
Undervoltage (Warning)	On	On	Slow
Overvoltage/Undervoltage Fault (Shutdown)	On	On	Quick
Overtemperature Fault (Shutdown)	On	On	Slow Alternating
Main Speed Potentiometer Fault (Shutdown)	On	On	Quick Alternating
Motor or Brake Fault (Shutdown)	On	On	Double Quick Alternating
Timed Current Limit (Shudown)	Off	On	Quick

*Flash Rate: Slow = 1 second on / 1 second off. Quick = 0.15 second on / 0.15 second off.

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