Actuators: relays & motors

Wroclaw University of Science and Technology

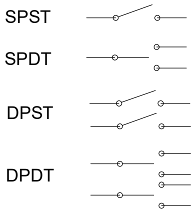
References

- S. L Herman, Industrial motor control, Clifton Park, 2014
- T. R. Kuphaldt, Lessons In Electric Circuits, Volume II – AC, 6th Edition, 2007 (http://www.faqs.org/docs/electric/AC/index.html)
- J. Przepiorkowski, Silniki elektryczne w praktyce elektronika, BTC

Outline

- relays
  - electromechanical
  - electronic relay (SSR – Solis State Relay)
- Electric motors

Relays

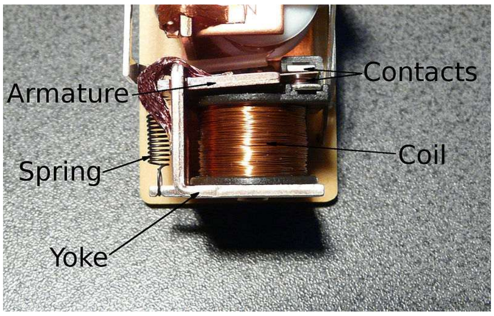


Single(Double)Pole

Single(Double;Triple)Throw

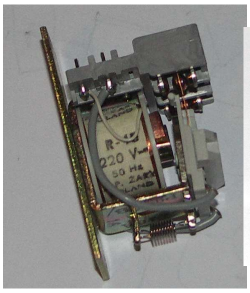
CO – centre off/change over
example
SPTT=SPCO

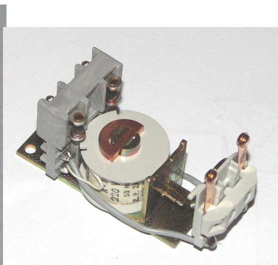
Relay



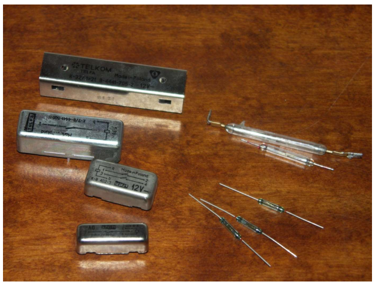
Relays

AC relay





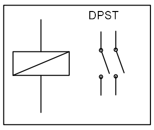
reed relay

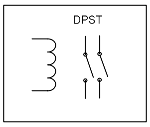


Relays - types

- Regular
- Latching (bistable)
- Polarized relay
- Reed relay
  - (mercury wetted)
- Contactor
- Solid state relay
  - transistor
  - triac
  - Thyristor
- Other (safety switches, over current,……)

Relay - diagram symbol





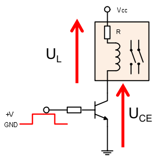
Ohm’s low for inductance

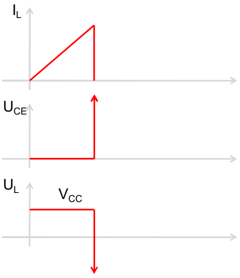
$$U_L = L\frac{dI}{dt}$$

$$U_L = X_L I_L = \frac{1}{i\omega C} I_L$$

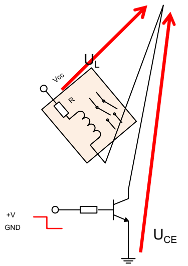
TIPS:
- higher voltage applied – faster changes of current
- fast changes in current – higher voltage induced
- when current change „slope direction” – voltage change polarity:
  - positive voltage applied – current increased
  - current decreased – negative voltage induced

Switching on and off an inductor





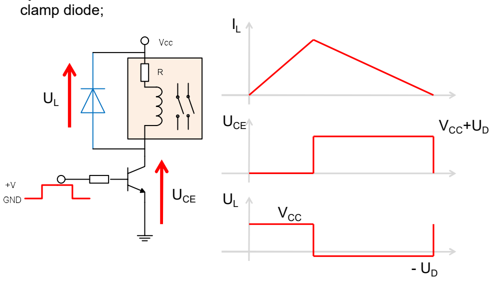
Relay – spark discharge



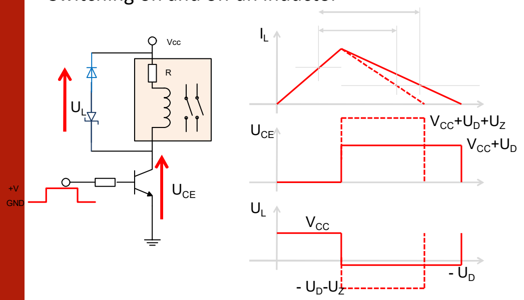
High voltage can destroy transistor and relay
and can be very dangerous !!!!

Switching on and off an inductor

protection diode;
flyback diode;
clamp diode;

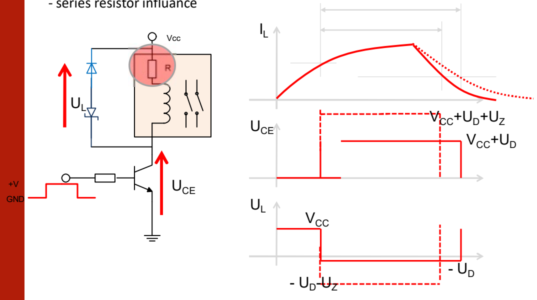


Switching on and off an inductor

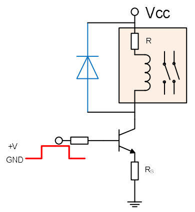


Switching on and off an inductor

- series resistor influance

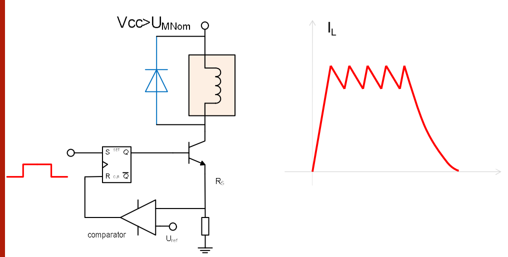


Decreasing rise time (off to on time)

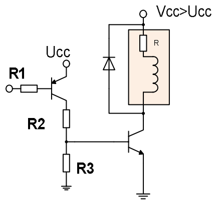


1. Increase Vcc
2. add Rs to preserve Imax
3. result=> higher power dissipation

Decreasing rise time with current limit

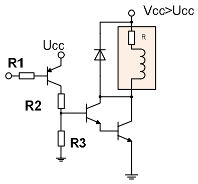


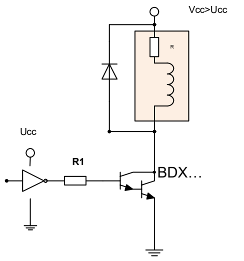
Driving relays and motors



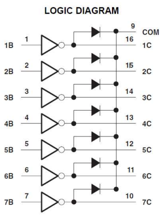
I<=1A

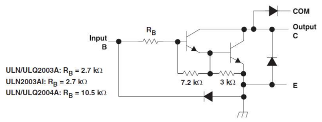
Driving relays and motors





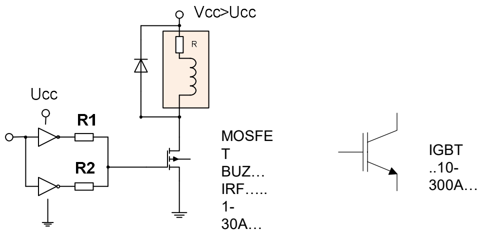
Darlington array ULN2004



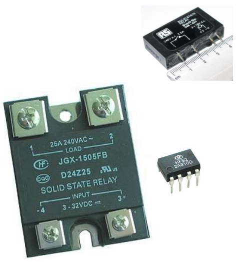


http://focus.ti.com/lit/ds/symlink/uln2004a.pdf

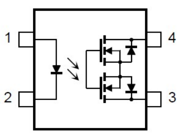
Driving relay/motor with MOSFET and IGBT

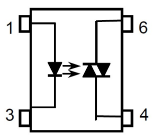


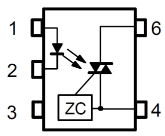
Solid State Relays (SSR)
Solid State Contactor (SSC)



SSR of different types
can be used for AC driven mechanical relays



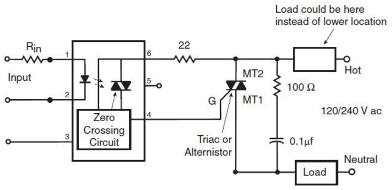




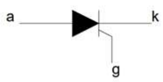
- Usually small power but can drive any type of load (including induction)
- AC and DC applications

- Be carfull with inductive load – the load can be not switched off !!!
- AC applications only

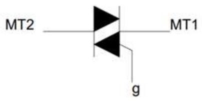
High power SSR



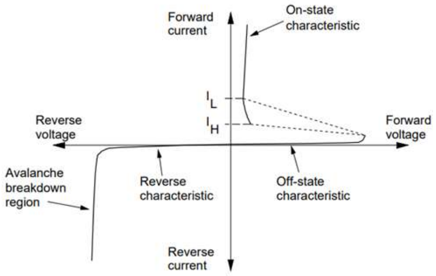
Thiristor



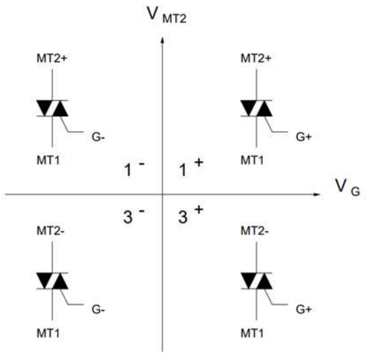
Triac



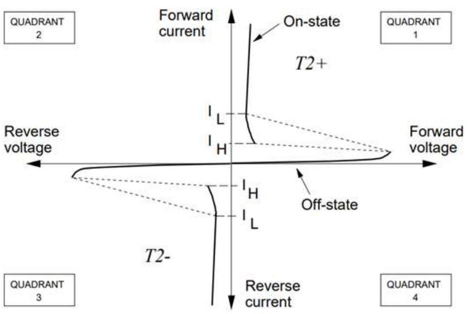
Thyristor V/I characteristic



Triac



Triac characteristic



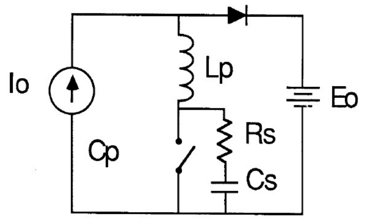
Important parameters:

gate current I_{GT}
latch current I_L
holding current I_H

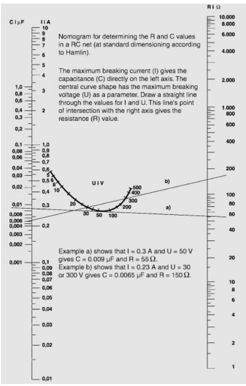
•Uncontrolled triac switching:

- Noise in the gate circuit (filter and shunt the gate)
- Exceeding dV_{COM}/dt (during switching off of the inductive load – snubber)
- Exceeding dI_{COM}/dt (unexpected current shutdown – uH inductance without saturation)
- Momentary exceeding of dV_D/dt (without permanent exceeding of V_{DRM} – network filtering; MOV)

RC snubber



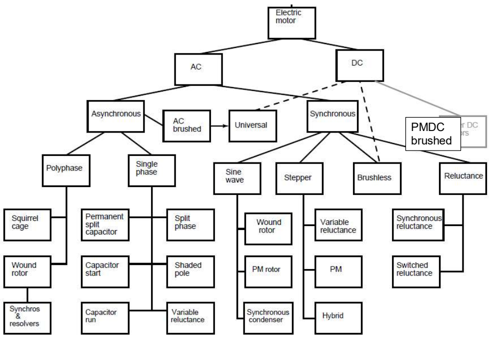
RC snubber



<30V – other load
>30V – over contacts

Protection elements:
- capacitive load
  - chock
  - NTC,
  - PTC(in series)
- induction load
  - surge arrester
  - varistor
  - transil

Motors



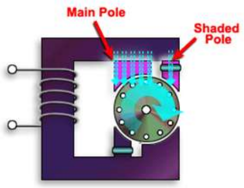
Electric motors

- AC motors
  - squirrel cage (3 phase, 1 phase -shade pole, cpacitor, split phase)
  - synchronous
- DC motors
  - Permanent magnet DC
  - Universal motors
    - series
    - shunt
    - compound wound
- BrushLess DC (BLDC)
  - 2 phase
  - 3 phase
- Stepper motors
  - reluctance
  - permanent magnet
  - hybrid
- Linear (Voice Coil Motor – VCM)

Type	Advantages	Disadvantages	Typical Application	Typical Drive
AC Induction (Shaded Pole) (31)	Least expensive Long life lowpower	Rotation slips from frequency Low starting torque	Fans	difficult tocontrol
AC Induction (split-phase capacitor) (34)	Medium power high starting torque	Rotation slips from frequency	Appliances Stationary Power Tools	Uni/Poly-phase AC
AC Squirrel cage 3ph (40)	High power	Rotation slips from frequency	Industry/ hp.mashines	Inverter frequency Vector controll (fr/current)
Brushed DC (41)	Low initial cost Simple speed control	Maintenance (brushes) Medium lifespan	Treadmill exercisers automotive motors (seats, blowers, windows)	Direct DC or PWM
BL DC (49)	Long lifespan low maintenance High efficiency	High initial cost Requires a controller	Hard drives CD/DVD players electric vehicles	DC switching, Pwm
Universal motor (61)	High starting torque, compact, high speed	Maintenance (brushes) Medium lifespan	Portable tools Grid powered	Uni-phase AC or Direct DC
Stepper DC 1ph/2ph (66)	Precision positioning High holding torque	High initial cost Requires a controller	Positioning in printers and floppy drives	DC switching
AC Synchronous (82)	Rotation in-sync with freq - hence no slip long-life	More expensive	Industrial motors Clocks Audio turntables tape drives	Uni/Poly-phase AC

Type	Advantages	Disadvantages	Typical Application	Typical Drive
AC Induction (Shaded Pole) (31)	Least expensive Long life lowpower	Rotation slips from frequency Low starting torque	Fans	difficult tocontrol
AC Induction (split-phase capacitor) (34)	Medium power high starting torque	Rotation slips from frequency	Appliances Stationary Power Tools	Uni/Poly-phase AC
AC Squirrel cage 3ph (40)	High power	Rotation slips from frequency	Industry/ hp.mashines	Inverter frequency Vector controll (fr/current)
Brushed DC (41)	Low initial cost Simple speed control	Maintenance (brushes) Medium lifespan	Treadmill exercisers automotive motors (seats, blowers, windows)	Direct DC or PWM
BL DC (49)	Long lifespan low maintenance High efficiency	High initial cost Requires a controller	Hard drives CD/DVD players electric vehicles	DC switching, Pwm
Universal motor (61)	High starting torque, compact, high speed	Maintenance (brushes) Medium lifespan	Portable tools Grid powered	Uni-phase AC or Direct DC
Stepper DC 1ph/2ph (66)	Precision positioning High holding torque	High initial cost Requires a controller	Positioning in printers and floppy drives	DC switching
AC Synchronous (82)	Rotation in-sync with freq - hence no slip long-life	More expensive	Industrial motors Clocks Audio turntables tape drives	Uni/Poly-phase AC

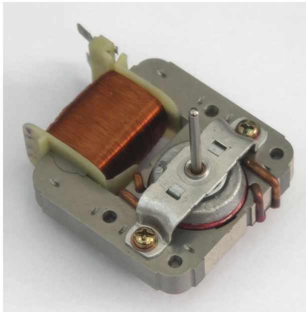
Shaded pole induction motor



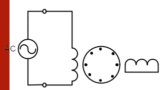
advantages
- •Very cheap and reliable
- •Extremely rugged in nature
- •Easy to construct

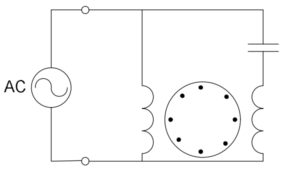
disadvantages
- •Low starting torque
- •Low efficiency

Shaded pole induction motor

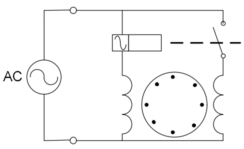


Capacitor Run
Permanent Split Capacitor(PSD Motor)

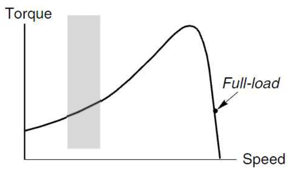




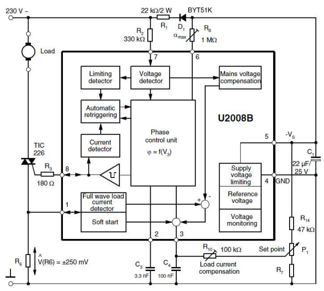
Split Phase Induction Motor



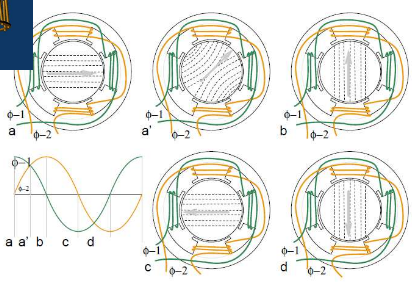
Induction Motor control by means of slip control



Induction Motor cc



Squirrel cage



Squirrel cage – drivig inverter

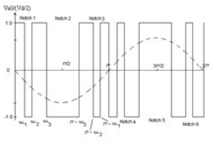


Fig 2 Programmed Harmonic Elimination of Fifth and Seventh Harmonics

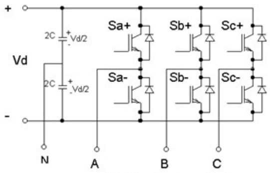


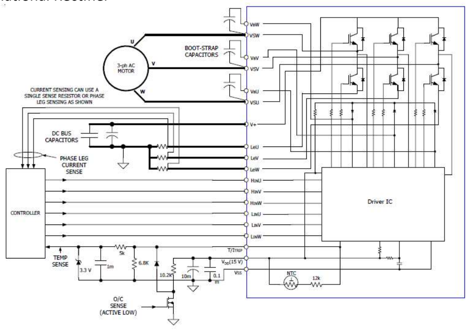
Fig 1 A Three Phase Inverter Circuit

46

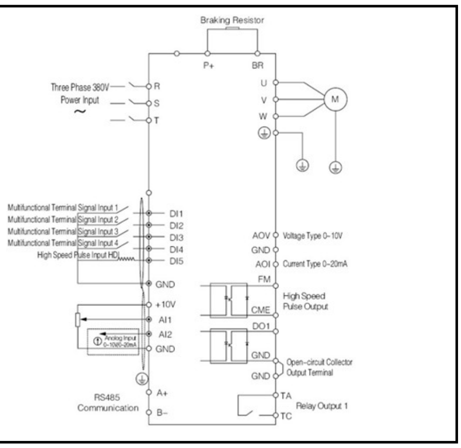
Inverter

IRAMS10UP60A

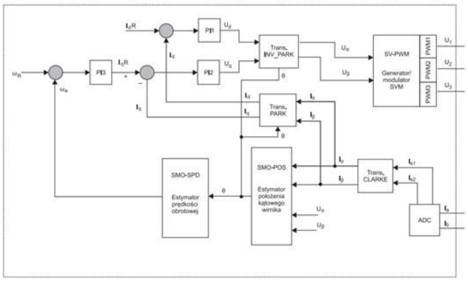
by International Rectifier

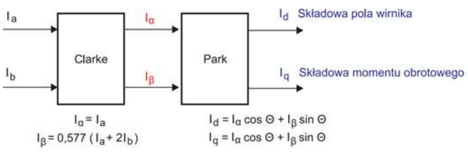


47



48





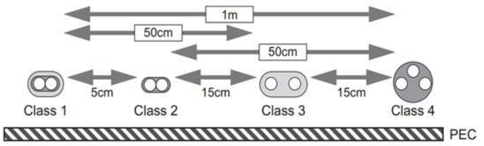
Braking resistor

$J = J_{Motor} + J_{Load}$ inertial momentum

$P_B = \frac{J\omega_B(\omega_B - \omega_0)}{t}$ Braking power

$R = \frac{V_{DC}^2}{P_B}$ Resistor

$P_{Res} = 1.30 * (P_B - P_{Inv})$ Resistor power



The cables from adjustable **speed inverter** drives to their motors may be specified by the drive manufacturers to have 600mm or more spacing from any other parallel run of cable (**drives are perhaps the noisiest devices on the planet!).**

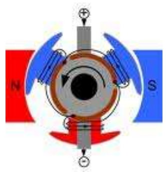
Figure from: Tim Williams, „EMC for Product Designers", Fifth edition, Elsevier, 2017

Type	Advantages	Disadvantages	Typical Application	Typical Drive
AC Induction (Shaded Pole) (31)	Least expensive Long life lowpower	Rotation slips from frequency Low starting torque	Fans	difficult tocontrol
AC Induction (split-phase capacitor) (34)	Medium power high starting torque	Rotation slips from frequency	Appliances Stationary Power Tools	Uni/Poly-phase AC
AC Squirrel cage 3ph (40)	High power	Rotation slips from frequency	Industry/ hp.mashines	Inverter frequency Vector controll (fr/current)
Brushed DC (41)	Low initial cost Simple speed control	Maintenance (brushes) Medium lifespan	Treadmill exercisers automotive motors (seats, blowers, windows)	Direct DC or PWM
BL DC (49)	Long lifespan low maintenance High efficiency	High initial cost Requires a controller	Hard drives CD/DVD players electric vehicles	DC switching, Pwm
Universal motor (61)	High starting torque, compact, high speed	Maintenance (brushes) Medium lifespan	Portable tools Grid powered	Uni-phase AC or Direct DC
Stepper DC 1ph/2ph (66)	Precision positioning High holding torque	High initial cost Requires a controller	Positioning in printers and floppy drives	DC switching
AC Synchronous (82)	Rotation in-sync with freq - hence no slip long-life	More expensive	Industrial motors Clocks Audio turntables tape drives	Uni/Poly-phase AC

55

DC motors

PMDC – Permanent Magnet DC



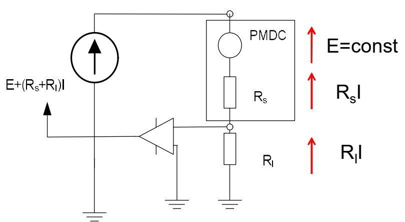
High starting torque,
compact,
high speed,
easy to controll,
cheap

Maintenance (brushes)
Medium lifetime,
Noisy
EMI emission

56

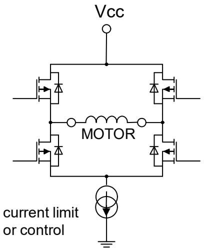
DC motors

PMDC – Permanent Magnet DC - control circuit



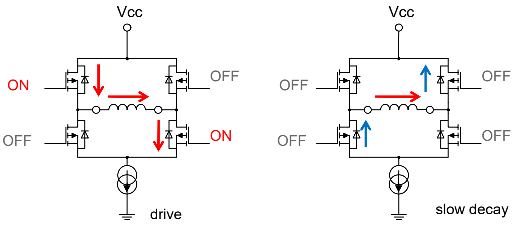
57

Direction controll - H bridge

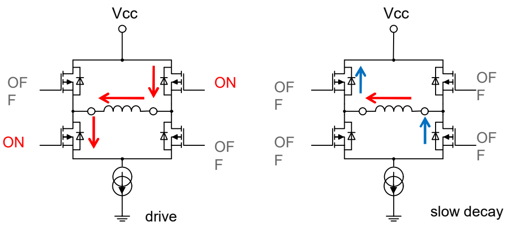


TIPS:
BJT, MOSFET, IGBT transistors can be used,
diodes cunduct self inductance currents

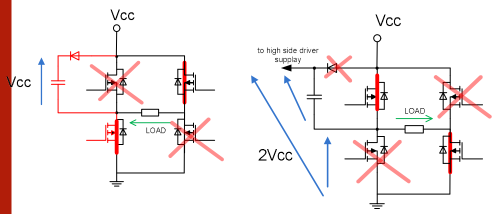
H bridge operation 1



H bridge operation 2



Bootstrapping



61

DC motors

PMDC – Permanent Magnet DC -ironless (coil and disc) -pancake

TIP:
very little momentum – fast start

http://www.kurz-motor.de/eproduktframetextgleichstromscheibenlaeufer.htm

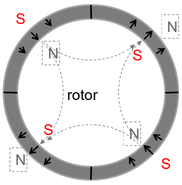
http://www.designworldonline.com/ArticleDetails.aspx?id=197
3

62

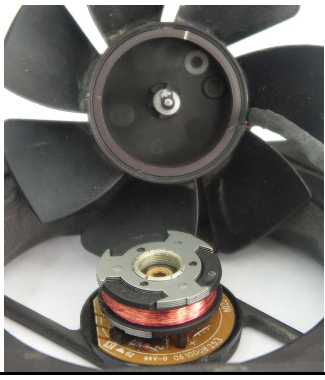
Type	Advantages	Disadvantages	Typical Application	Typical Drive
AC Induction (Shaded Pole) (31)	Least expensive Long life lowpower	Rotation slips from frequency Low starting torque	Fans	difficult tocontrol
AC Induction (split-phase capacitor) (34)	Medium power high starting torque	Rotation slips from frequency	Appliances Stationary Power Tools	Uni/Poly-phase AC
AC Squirrel cage 3ph (40)	High power	Rotation slips from frequency	Industry/ hp.mashines	Inverter frequency Vector controll (fr/current)
Brushed DC (41)	Low initial cost Simple speed control	Maintenance (brushes) Medium lifespan	Treadmill exercisers automotive motors (seats, blowers, windows)	Direct DC or PWM
BL DC (49)	Long lifespan low maintenance High efficiency	High initial cost Requires a controller	Hard drives CD/DVD players electric vehicles	DC switching, Pwm
Universal motor (61)	High starting torque, compact, high speed	Maintenance (brushes) Medium lifespan	Portable tools Grid powered	Uni-phase AC or Direct DC
Stepper DC 1ph/2ph (66)	Precision positioning High holding torque	High initial cost Requires a controller	Positioning in printers and floppy drives	DC switching
AC Synchronous (82)	Rotation in-sync with freq - hence no slip long-life	More expensive	Industrial motors Clocks Audio turntables tape drives	Uni/Poly-phase AC

63

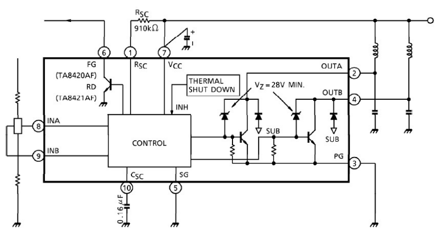
BLDC (BrushLess DC) motors



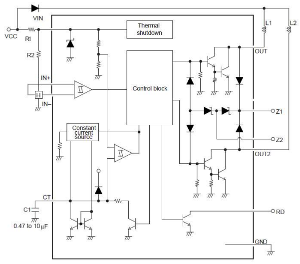
BLDC
1 phase



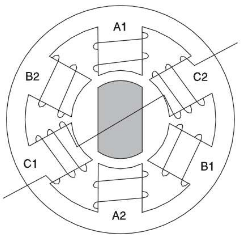
TA8420/21 BLDC 2 phase driver



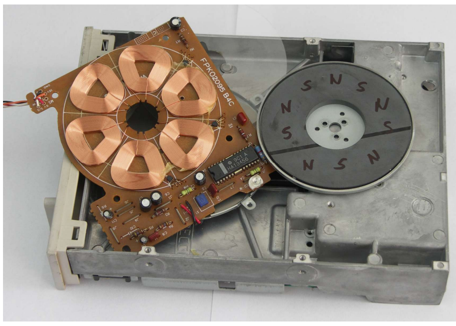
LB1864 2 phase BLDC driver



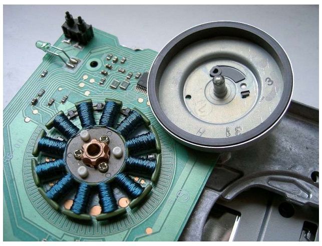
3 phase BLDC



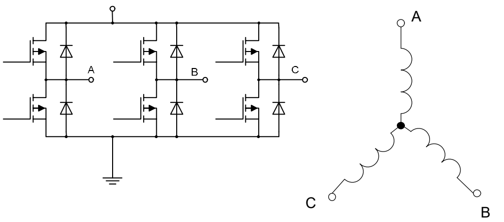
BLDC



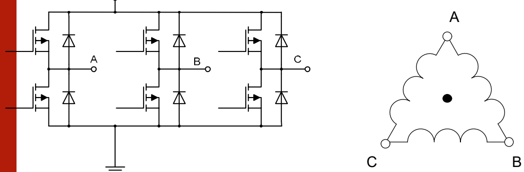
BLDC



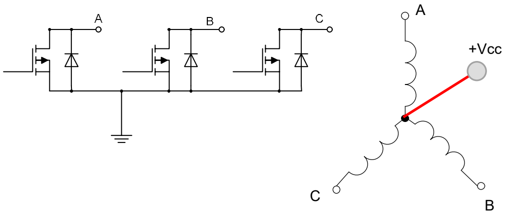
BLDC – bipolar driving - star



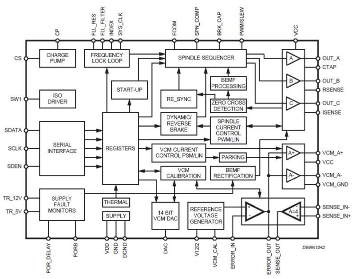
BLDC – bipolar driving - triangle



BLDC – unipolar driving - star

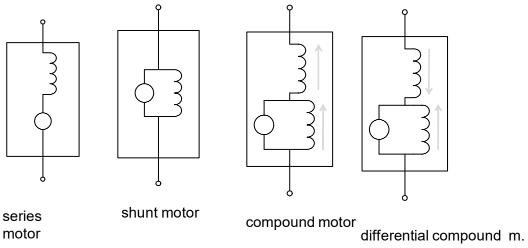


L6268 driver BLCD + VCM(voice-coil-motor) (ST)

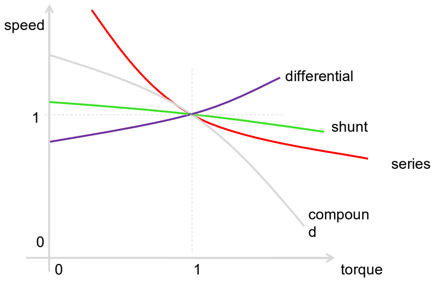


Type	Advantages	Disadvantages	Typical Application	Typical Drive
AC Induction (Shaded Pole) (31)	Least expensive Long life lowpower	Rotation slips from frequency Low starting torque	Fans	difficult tocontrol
AC Induction (split-phase capacitor) (34)	Medium power high starting torque	Rotation slips from frequency	Appliances Stationary Power Tools	Uni/Poly-phase AC
AC Squirrel cage 3ph (40)	High power	Rotation slips from frequency	Industry/ hp.mashines	Inverter frequency Vector controll (fr/current)
Brushed DC (41)	Low initial cost Simple speed control	Maintenance (brushes) Medium lifespan	Treadmill exercisers automotive motors (seats, blowers, windows)	Direct DC or PWM
BL DC (49)	Long lifespan low maintenance High efficiency	High initial cost Requires a controller	Hard drives CD/DVD players electric vehicles	DC switching, Pwm
Universal motor (61)	High starting torque, compact, high speed	Maintenance (brushes) Medium lifespan	Portable tools Grid powered	Uni-phase AC or Direct DC
Stepper DC 1ph/2ph (66)	Precision positioning High holding torque	High initial cost Requires a controller	Positioning in printers and floppy drives	DC switching
AC Synchronous (82)	Rotation in-sync with freq - hence no slip long-life	More expensive	Industrial motors Clocks Audio turntables tape drives	Uni/Poly-phase AC

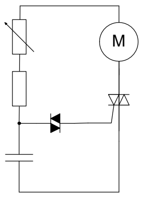
Permanent magnet replaced by electromagnet – universal motor



Torque vs. speed

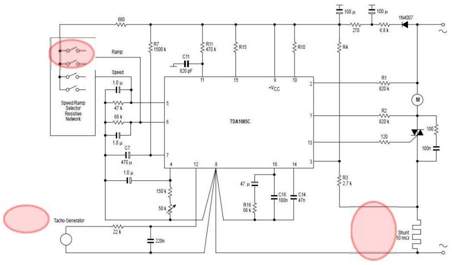


Universal motor – driver / controller



Tips:
1. voltage controlled
2. direction can be changed by switching stator or rotor winding
3. the example shown is the most simple

Universal motor – driver/controller more sophisticated example



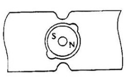
From Motorola materials
(now ON Semiconductor)

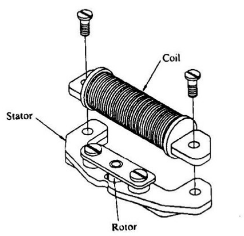
79

Type	Advantages	Disadvantages	Typical Application	Typical Drive
AC Induction (Shaded Pole) (31)	Least expensive Long life lowpower	Rotation slips from frequency Low starting torque	Fans	difficult tocontrol
AC Induction (split-phase capacitor) (34)	Medium power high starting torque	Rotation slips from frequency	Appliances Stationary Power Tools	Uni/Poly-phase AC
AC Squirrel cage 3ph (40)	High power	Rotation slips from frequency	Industry/ hp.mashines	Inverter frequency Vector controll (fr/current)
Brushed DC (41)	Low initial cost Simple speed control	Maintenance (brushes) Medium lifespan	Treadmill exercisers automotive motors (seats, blowers, windows)	Direct DC or PWM
BL DC (49)	Long lifespan low maintenance High efficiency	High initial cost Requires a controller	Hard drives CD/DVD players electric vehicles	DC switching, Pwm
Universal motor (61)	High starting torque, compact, high speed	Maintenance (brushes) Medium lifespan	Portable tools Grid powered	Uni-phase AC or Direct DC
Stepper DC 1ph/2ph (66)	Precision positioning High holding torque	High initial cost Requires a controller	Positioning in printers and floppy drives	DC switching
AC Synchronous (82)	Rotation in-sync with freq - hence no slip long-life	More expensive	Industrial motors Clocks Audio turntables tape drives	Uni/Poly-phase AC

80

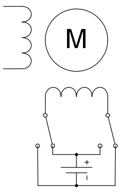
Clock motor



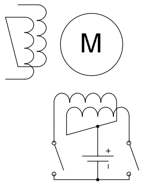


81

stepper motors- bi/uni-polar

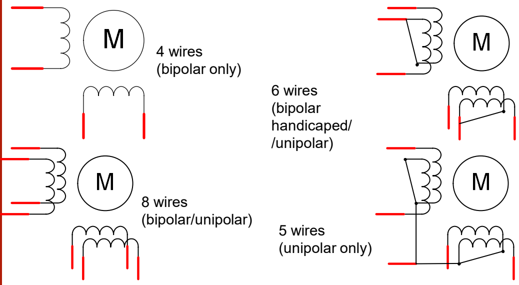


bipolar winding
H bridge needed

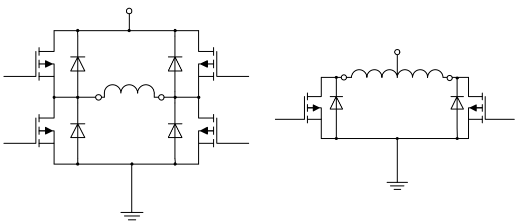


unipolar winding
single swich

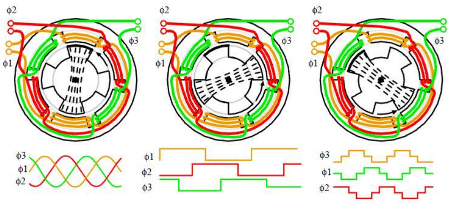
(2 phase) steppper motor internal conections



Unipolar/Bipolar stepper motor driving



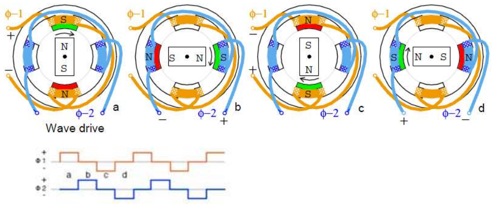
Steppper motor – reluctance motor



Lessons In Electric Circuits, Volume II – AC By Tony R. Kuphaldt, Sixth Edition, last update July 25, 2007

85

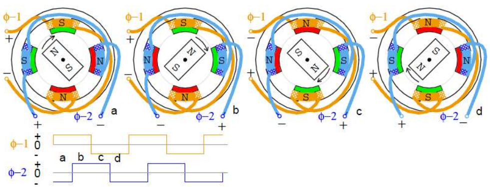
Permanent magnet motor wave driving



Lessons In Electric Circuits, Volume II – AC By Tony R. Kuphaldt, Sixth Edition, last update July 25, 2007

86

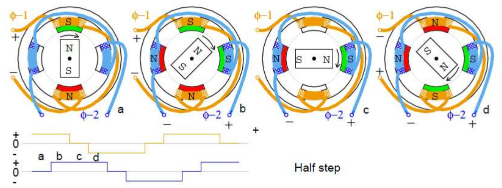
Permanent magnet motor full step driving



Lessons In Electric Circuits, Volume II – AC By Tony R. Kuphaldt, Sixth Edition, last update July 25, 2007

87

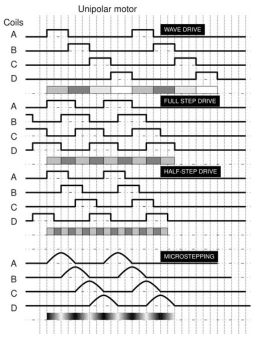
Permanent magnet motor half step driving



Lessons In Electric Circuits, Volume II – AC By Tony R. Kuphaldt, Sixth Edition, last update July 25, 2007

88

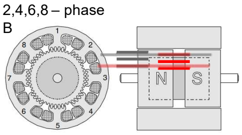
Full/microstep driving



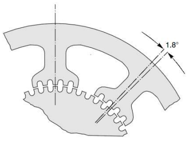
89

Hybrid motor

1,3,5,7 – phase A
2,4,6,8 – phase B

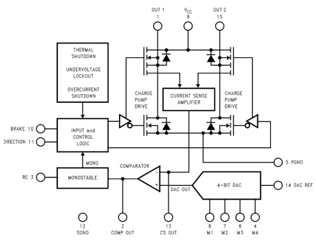


$$Step = \frac{360\deg}{N_{teeth} \cdot N_{phases}}$$

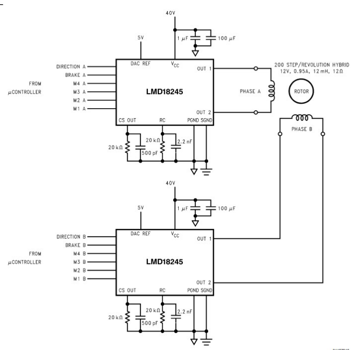


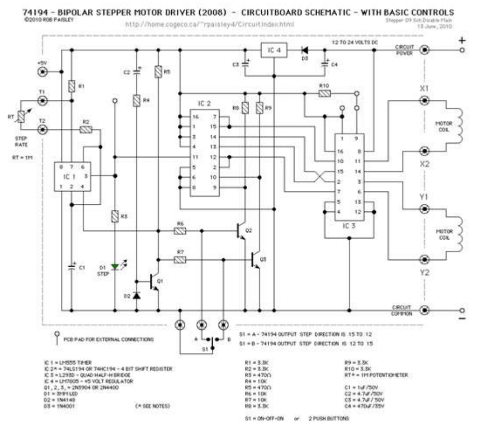
90

LMD18245 3A, 55V DMOS Full-Bridge Motor Driver – National Instrument

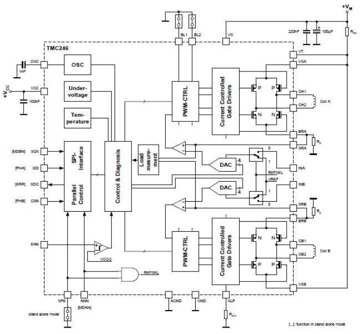


LMD18245 applicatio

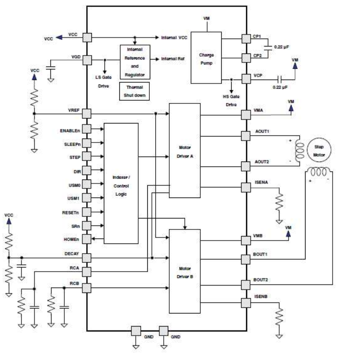




TMC246

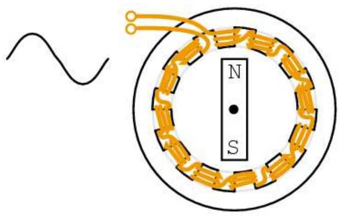


DRV8811
TI



Type	Advantages	Disadvantages	Typical Application	Typical Drive
AC Induction (Shaded Pole) (31)	Least expensive Long life lowpower	Rotation slips from frequency Low starting torque	Fans	difficult tocontrol
AC Induction (split-phase capacitor) (34)	Medium power high starting torque	Rotation slips from frequency	Appliances Stationary Power Tools	Uni/Poly-phase AC
AC Squirrel cage 3ph (40)	High power	Rotation slips from frequency	Industry/ hp.mashines	Inverter frequency Vector controll (fr/current)
Brushed DC (41)	Low initial cost Simple speed control	Maintenance (brushes) Medium lifespan	Treadmill exercisers automotive motors (seats, blowers, windows)	Direct DC or PWM
BL DC (49)	Long lifespan low maintenance High efficiency	High initial cost Requires a controller	Hard drives CD/DVD players electric vehicles	DC switching, Pwm
Universal motor (61)	High starting torque, compact, high speed	Maintenance (brushes) Medium lifespan	Portable tools Grid powered	Uni-phase AC or Direct DC
Stepper DC 1ph/2ph (66)	Precision positioning High holding torque	High initial cost Requires a controller	Positioning in printers and floppy drives	DC switching
AC Synchronous (82)	Rotation in-sync with freq - hence no slip long-life	More expensive	Industrial motors Clocks Audio turntables tape drives	Uni/Poly-phase AC

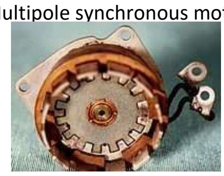
Synchronous motor

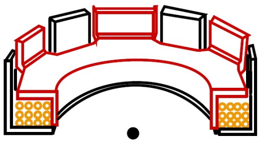


97

Lessons In Electric Circuits, Volume II – AC By Tony R. Kuphaldt, Sixth Edition, last update July 25, 2007

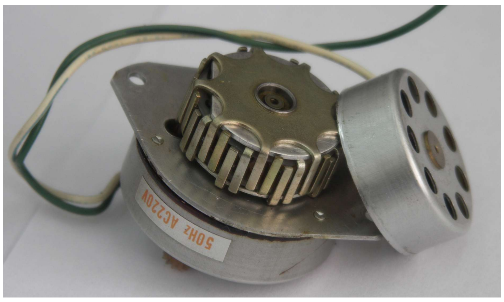
Multipole synchronous motor





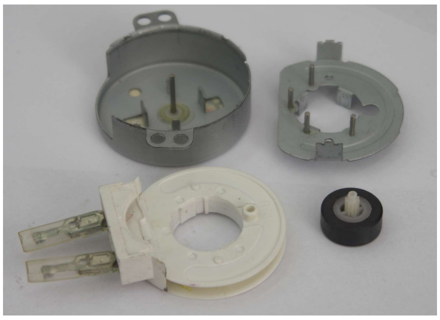
The inductionf or self starting
and the bar magnet as synchronous motor

98

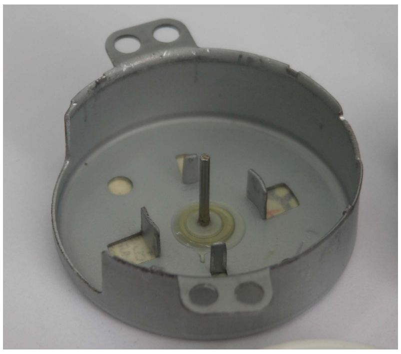


99

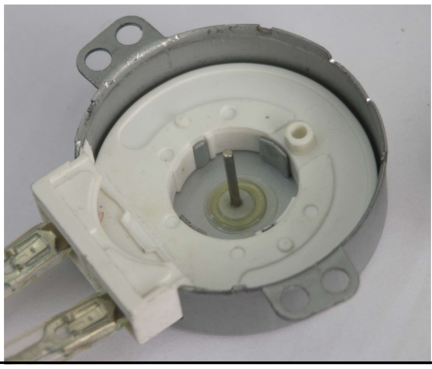
Synchronous motor



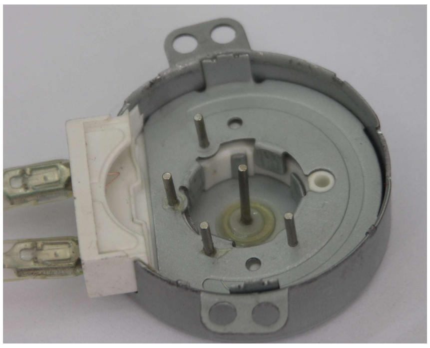
100



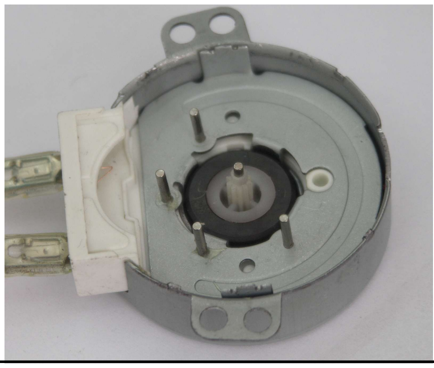
101



102



103



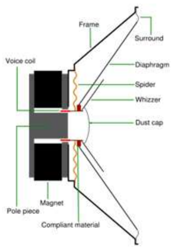
104

Synchronous motor
plat drive of microwave

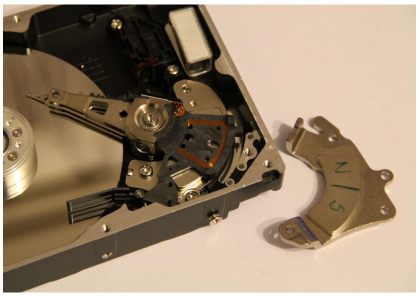
105

VCM
Voice Coil Motor

VCM motors (actuators)
(hard disk head, laser positioner in CD)



Linear motor



Type	Advantages	Disadvantages	Typical Application	Typical Drive
AC Induction (Shaded Pole) (31)	Least expensive Long life lowpower	Rotation slips from frequency Low starting torque	Fans	difficult tocontrol
AC Induction (split-phase capacitor) (34)	Medium power high starting torque	Rotation slips from frequency	Appliances Stationary Power Tools	Uni/Poly-phase AC
AC Squirrel cage 3ph (40)	High power	Rotation slips from frequency	Industry/ hp.mashines	Inverter frequency Vector controll (fr/current)
Brushed DC (41)	Low initial cost Simple speed control	Maintenance (brushes) Medium lifespan	Treadmill exercisers automotive motors (seats, blowers, windows)	Direct DC or PWM
BL DC (49)	Long lifespan low maintenance High efficiency	High initial cost Requires a controller	Hard drives CD/DVD players electric vehicles	DC switching, Pwm
Universal motor (61)	High starting torque, compact, high speed	Maintenance (brushes) Medium lifespan	Portable tools Grid powered	Uni-phase AC or Direct DC
Stepper DC 1ph/2ph (66)	Precision positioning High holding torque	High initial cost Requires a controller	Positioning in printers and floppy drives	DC switching
AC Synchronous (82)	Rotation in-sync with freq - hence no slip long-life	More expensive	Industrial motors Clocks Audio turntables tape drives	Uni/Poly-phase AC

109

Summary

- Electromechanical relays
- SSR
- AC motors
  - squirrel cage (3 phase, shade pole, capacitor, split phase)
  - synchronous
- DC motors
  - Permanent magnet DC
  - Universal motors
- Brushless DC (BLDC)
- Step motors
- Linear (Voice Coil Motor – VCM)

110

Sample test question:

1. Explain the role of the protective diode (flyback diode, clamping diode) in the case of an inductive load.
2. Name the types of solid state relays
3. Match the appropriate motor to its characteristics and application.

111