TI 馬達驅動和控制研討會

台北 9月25日

台中 9月26日　高雄 9月27日

Texas Instruments

TI Spins Motors

Andy Liang

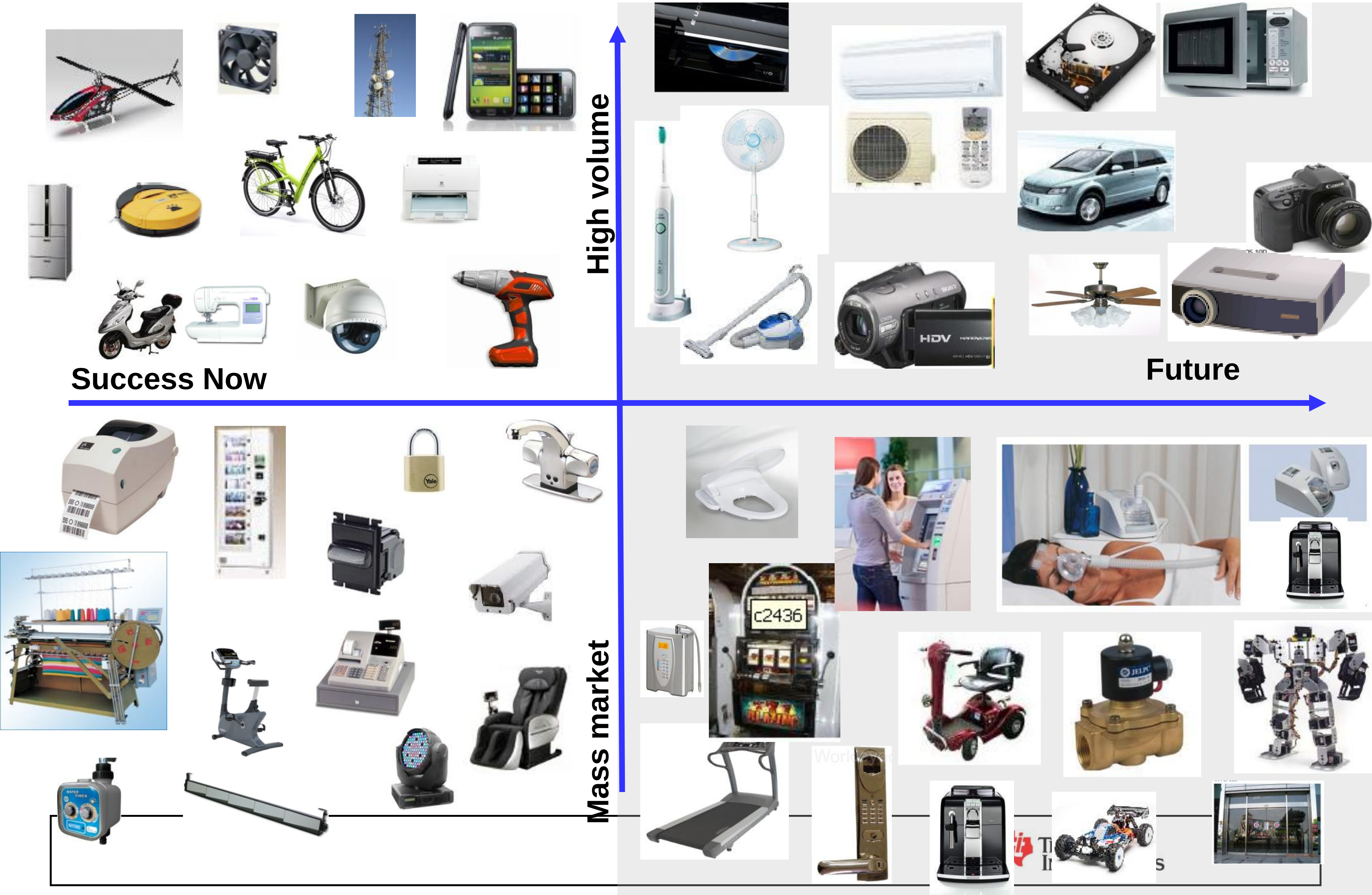
Asia Business Development

2012, Sep

Agenda

- **Motor related EE overview**
- **Motors that TI drives**
- **TI technology & features**
  - Motor in Portable EE (VCM)
  - Motor in Portable EE (Touch Feedback)
  - Piezo Cooling Fan
  - Actuators (relay, valve & solenoid)
  - BLDC, DC motor & Stepper

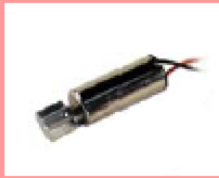
Motor Related End Equipment



Motors that TI Drives

Portable

DRV201
- Voice coil motor driver
- W/ RC and PWM/Linear o/p.



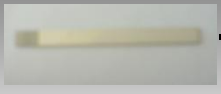
DRV8601
- ERM Motor Driver
- Overdrive ready

DRV2603
- LRA Driver
- Auto resonate detect

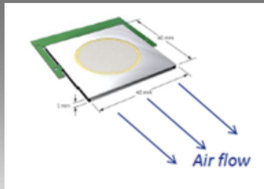
DRV2665
- Piezo Motor Driver (Module)
- 200Vpp from 3.3V Vcc

Cooling

DRV10866
- 5V, 3 Phase BLDC fan driver



DRV8662
- 200 Vp-p SL Piezo Cooler Driver

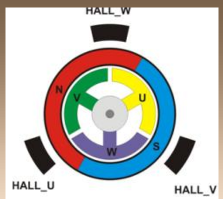


DRV266x
- 200 Vp-p SL Piezo Cooler Driver
- Integrated Digital Front End

General Motors/Actuators

DRV8832
- DC motor driver
- w/ buck features

DRV8818
- Stepper driver
- Low RDs on



DRV8301
- BLDC gate driver
- W/ Amp

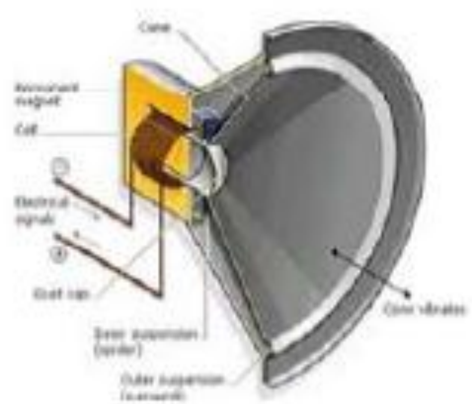
DRV110
- Relay driver
- Close loop control

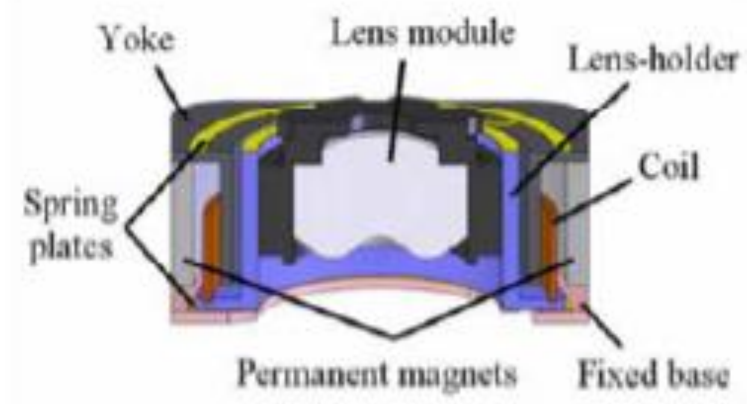
High Profile Actuators → Low Profile Actuators

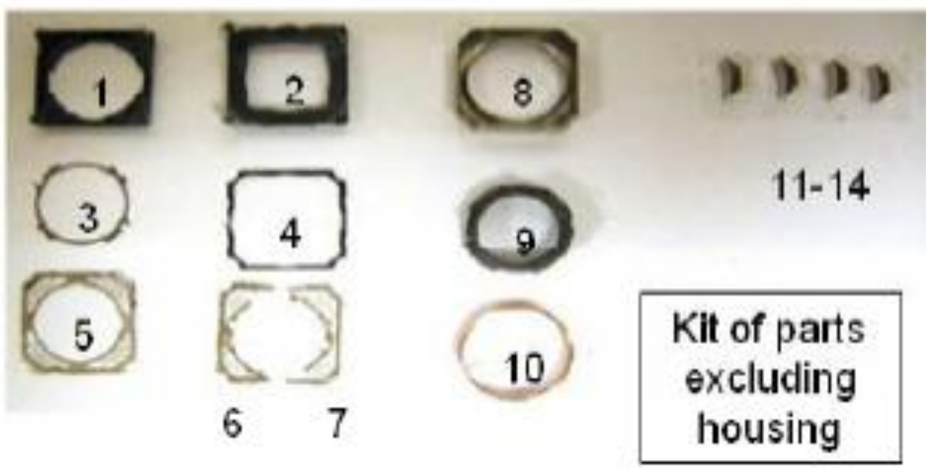
Motors in Portable EE (VCM)

VCM Voice Coil Motor

The Voice Coil Motor (VCM) > 99% Market Share





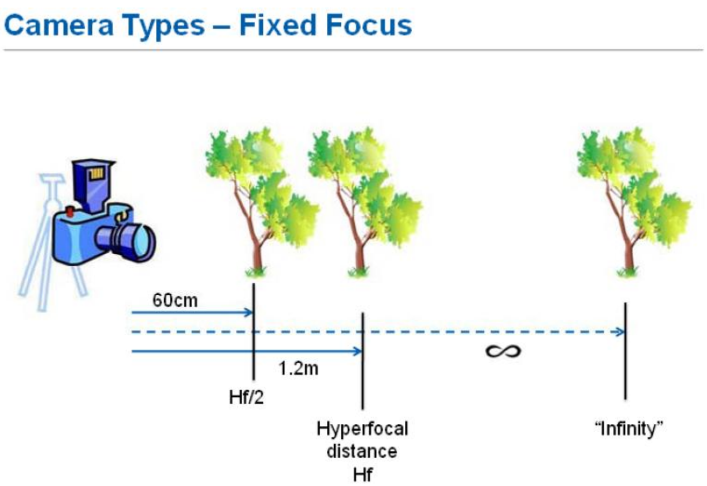


Domestic Supplier:

TDK Taiwan, Wahorng Tainan

Motors in Portable EE Why VCM?

- Auto-Focus (AF) automatically adjusts the optical system in a camera to ensure that the picture is sharp independent of the distance to the object
  - Active AF systems measure distance to the subject using a range finder, and subsequently adjust the optical system for correct focus
  - Passive AF systems determine focus position by analyzing the image while the optical system is adjusted for correct focus
- Cell phone cameras use passive AF due to advantages in size and cost



VCM Technology issues

Advantages

- Small
- Silent
- Large stroke
- Mature, established and well understood technology

Limitations

- Slow (~50ms including settling time)

VCM Market trend

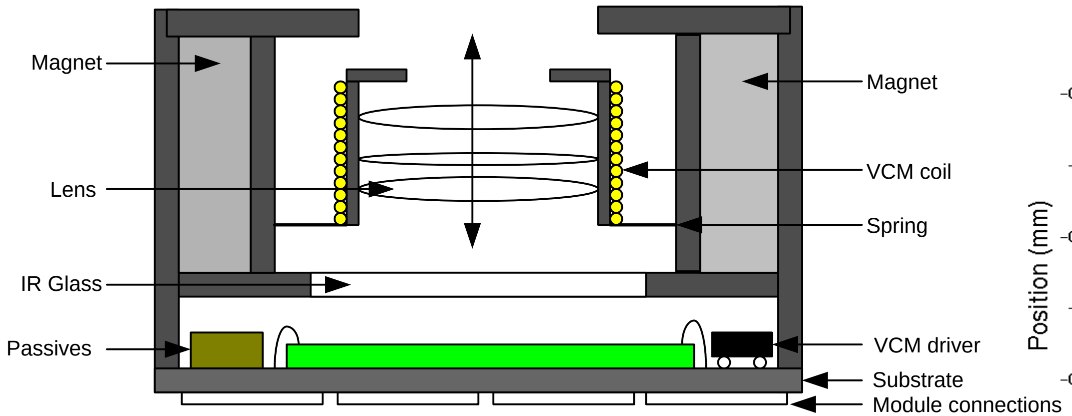
年次	2005	2006	2007	2008	2009	2010	2011～
コンパクトDSC	8M	10M	12M	14M	→	高画素化が鈍化	
携帯電話 画素数	CIF～3.2M →	5M		8M	10M → 12M	14M	16M
AF搭載率		→	20%	25%	30%	35%	更に増加
光学ｽﾞｰﾑ搭載率					→	1%＞	→
OIS搭載率						→	1%＞

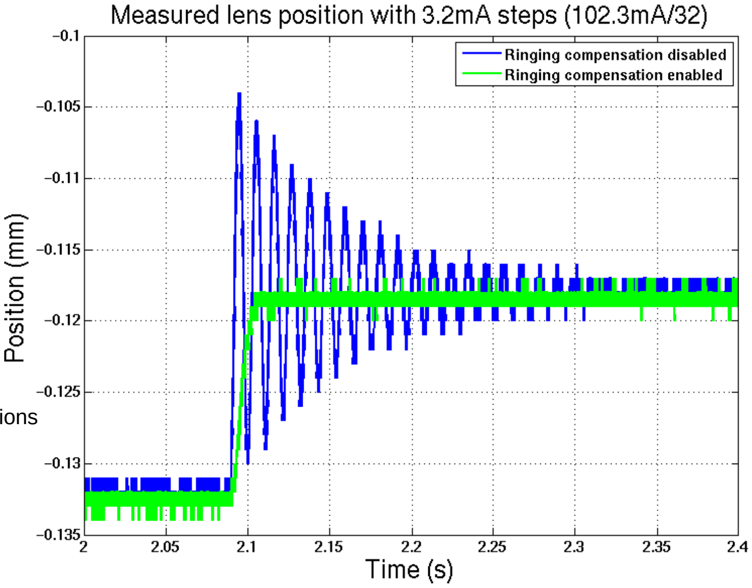
- ✓ 2010年中に14Mのモデルが投入される見通し。コンパクトDSCの画素競争が停滞しているため、画素数の差は埋まりつつある。
- ✓ 光学ズームや光学手振れ補正は依然としてコンパクトDSCならではの機能であり、モバイルカメラでの搭載率UPはまだ先である。

Fuji Chimera Research Institute, Inc.

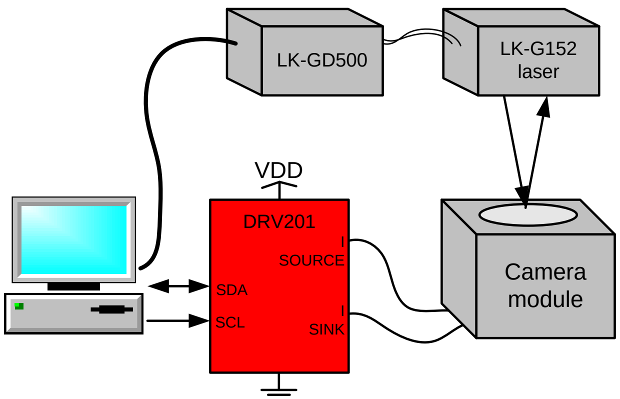
DRV201

Ringing Compensation Enabling Fast Auto Focus Algorithms





- Lens stack, spring, and VCM coil act as a dampened resonator.
- Ringing compensation allows lens settling in 10mS compared to 150mS without ringing compensation.
- DRV201 ringing compensation algorithm can tolerate ±10% or ±20% variation in VCM resonance frequency depending on the settling time bit.
- DRV201 ringing compensation supports wide range of VCM actuators and resonance frequency can be trimmed with SW.



Lens position measurement setup.

VCM

Advantages

- Small
- Silent
- Large stroke
- Mature, established and well understood technology

Limitations

- Slow (~50ms including settling time)
- High power consumption, typically 80-250mW

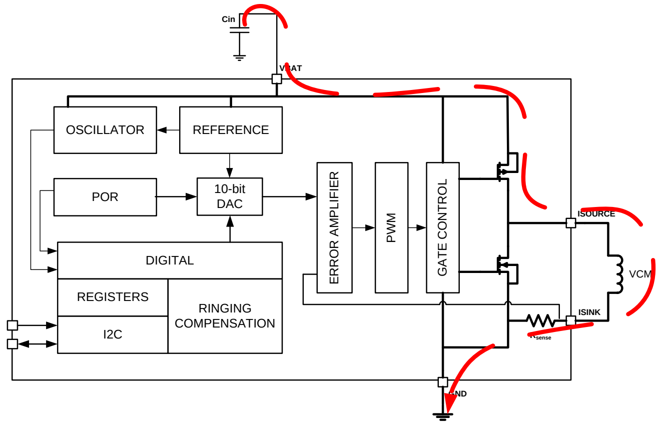
VCM why continuous AF?

The Need for Embedded Video Processing (continuous AF)

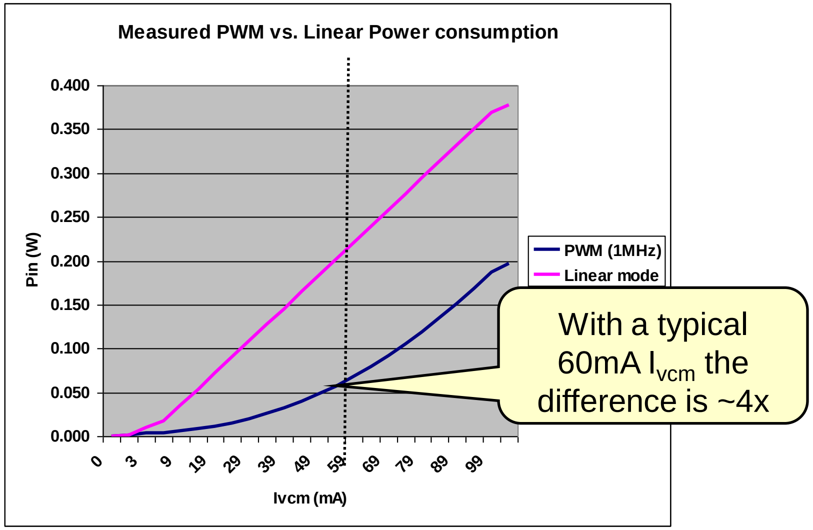
- Tremendous growth in video in the last decade
- Video capture and sharing is rapidly growing in popularity – over 20 hours of video uploaded to YouTube every minute
- HD video is becoming the expected norm
- Connectivity (wired or wireless) between HD capture & display devices
- HD video capture is being deployed in a wide range of devices – cameras, camcorders and cell phones
  - Few consumers want to download & edit videos
  - Few consumers want to edit in camera
  - Enable “ready-for-sharing” videos

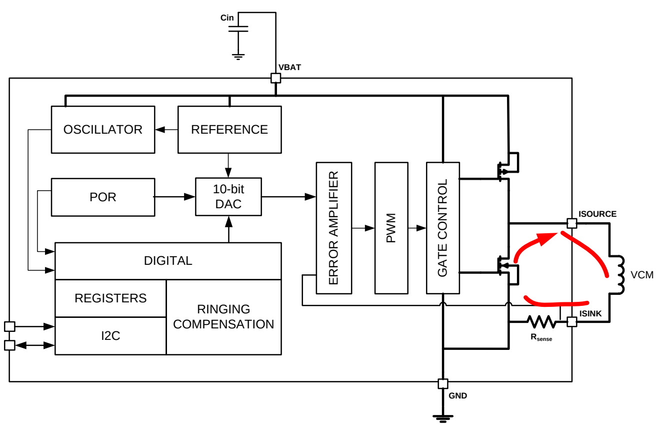
DRV201

PWM Current Generation Enabling High Efficiency VCM AF

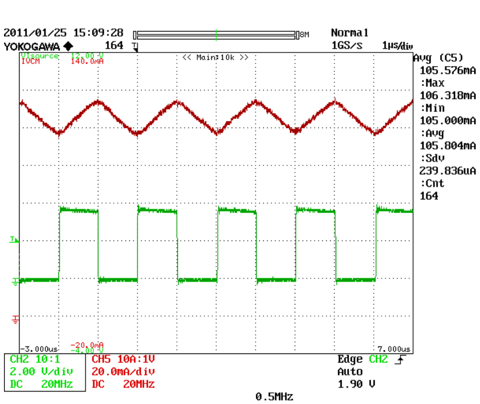


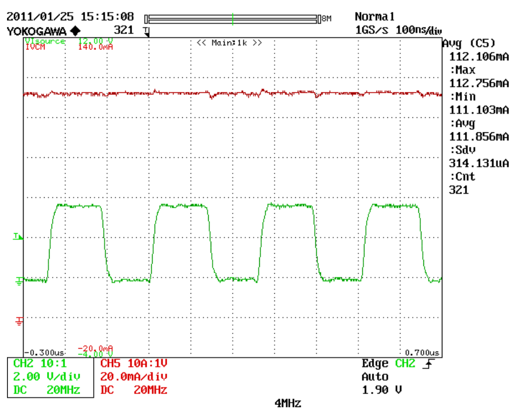
- Phase 1. VCM is shorted between VBAT and GND





- Phase 2. VCM is shorted into 'free wheeling' mode





- VCM current and ISOURCE node voltage waveforms with 500kHz and 4MHz PWM frequency

TEXAS INSTRUMENTS

TI Success Driving Voice Coil Motor

NOKIA

acer

Lumens™
Brighter Teaching

htc
quietly brilliant

ASUS®

VCM New Market

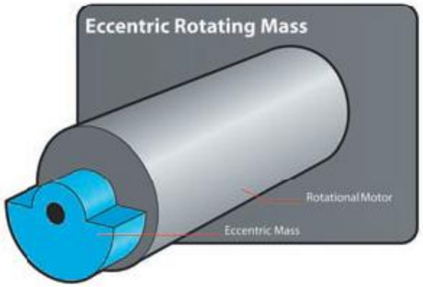
1 Billion+ Units Today
(< $2 per VGA Camera)

3+ Billion Units Per Year
within 5 Years

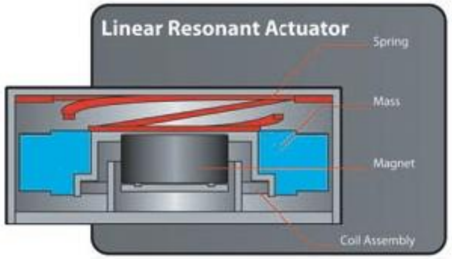
Motors in Portable EE

(Touch Feedback = Haptics)

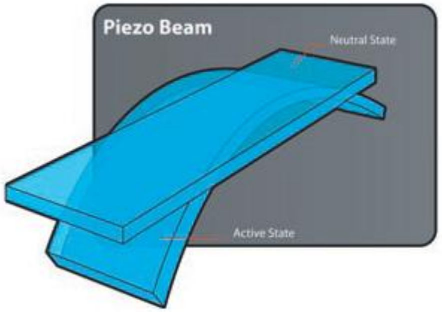
Motors for Touch feedback



ERM



LRA



Piezo

Other Proprietary Technologies

Why Touch Feedback?

- Humans perceive surfaces primarily through the sense of touch

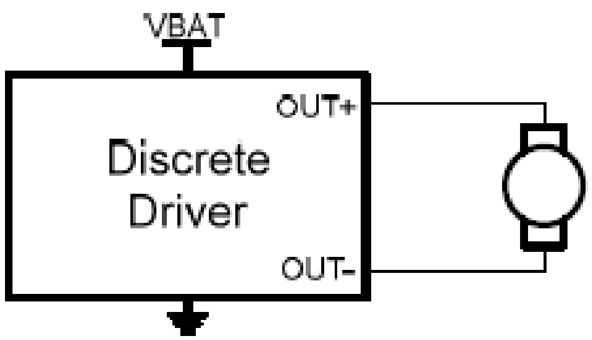

- Human touch is most sensitive under 300Hz

- Haptics can simulate different surfaces and effects by varying the shape, frequency, amplitude and duration of a vibration

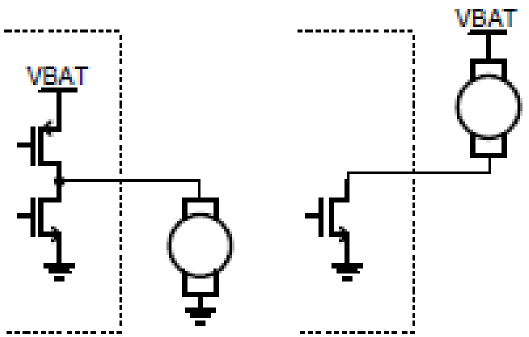
	Neurons	"Data" Rate (bits/s)	Temporal Acuity
Touch (Fingertip)	$\sim10^6$	10^2	5 ms
Hearing	$\sim10^4 – 10^5$	10^4	0.01 ms
Sight	$\sim10^6$	$10^6 – 10^9$	25 ms

Touch feedback v.s. Traditional Vibra

- Differential outputs allow reverse drive for braking ✓



- Single-ended output can only drive the motor in one direction



Traditional Vibra (ERM) Issues

•Slow

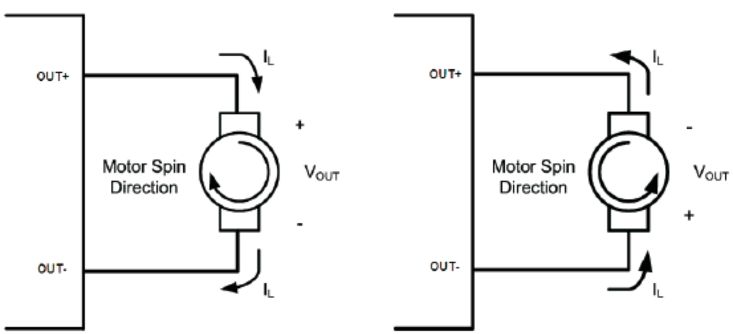
•Size/Height

•Sharpness

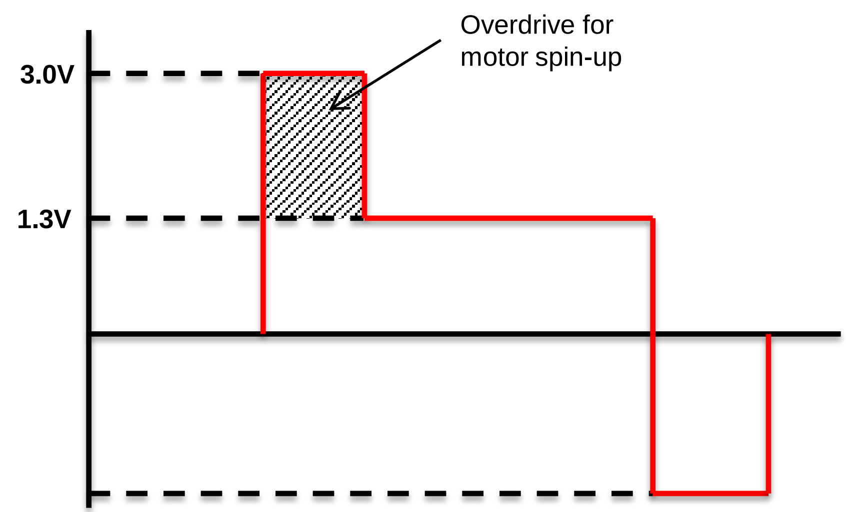
•Target ~ 50g weight

ERM Motors TI Accelerate ERM!

- Overdriving spins the motor quicker creating a faster response time
- Reverse driving the motor will help **eliminate uncontrolled vibrations** which are undesirable in most haptics effects
- The motor direction is changed by varying the polarity of the DC voltage which requires a **differential output**

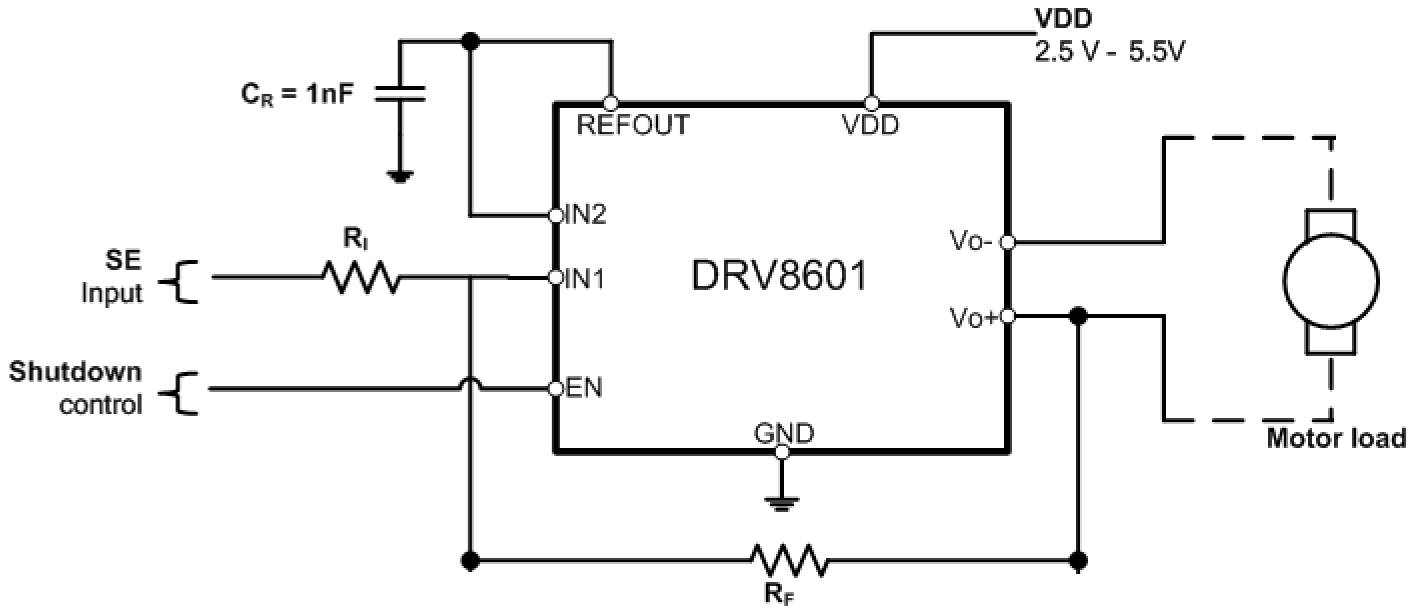


ERM Motor Direction



Driver Output

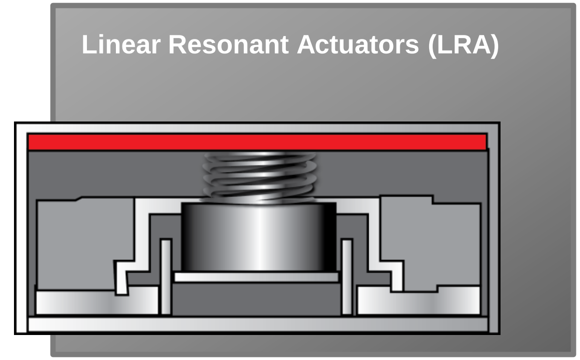
DRV8601 Over Driving ERM

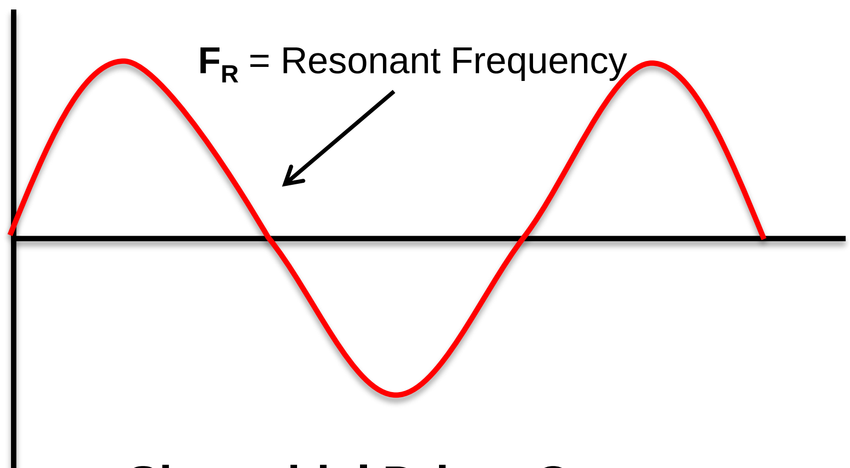


Configuration: Pseudo-differential Feedback with Internal Reference.
For Other Configurations, see http://www.ti.com/product/drv8601

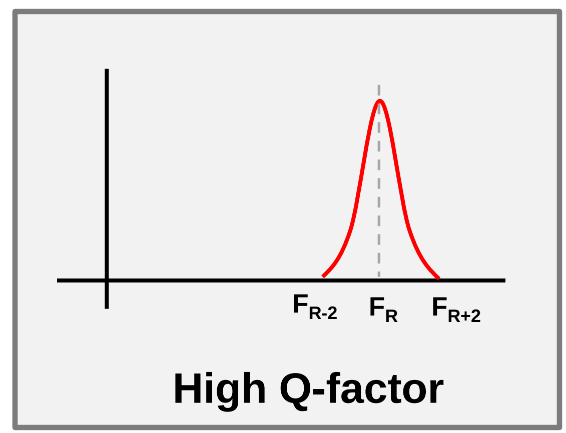
LRA Motors

- A Linear Resonant Actuator (LRA) is a spring + mass that vibrates in a linear motion
- Linear actuators must be driven at a narrow band (±2 Hz) around the **resonant frequency** because of the spring constant
- Using **auto resonance** to detect the resonant frequency will help increase performance





Sinusoidal Driver Output



LRA Frequency Response

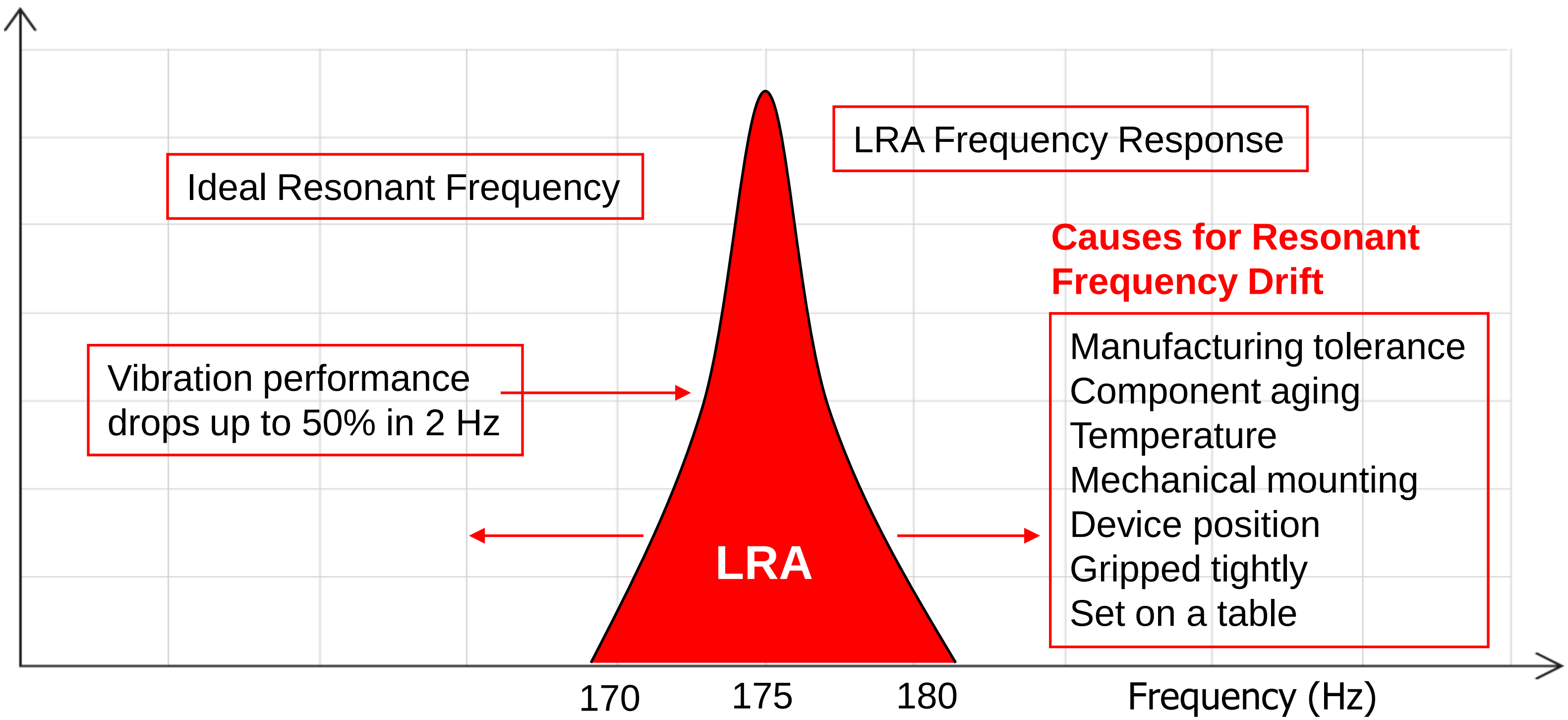
LRA Motor challenge: resonate frequency changes…

- Hooke's law of elasticity states $F = -k * x$
  - F = restoring force exerted by the spring to return to equilibrium
  - x = displacement distance from equilibrium
  - k = spring constant, affecting rate of change in spring
- The spring constant is tied to the physical properties that affect a spring
  - Temperature, load, process variation in manufacture, etc.
- The mass m of the LRA defines the resonant frequency f_r as:
  - $f_r = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$
- Thus proving the resonant frequency changes with the spring constant.

DRV2603 tracks LRA resonate frequency

- DRV2603 detects the LRA resonant frequency, allowing support of any LRA
- Supply current is up to 50% lower when driving at resonance
- LRA braking is only possible with auto-resonance tracking (braking provides crisper and sharper effects)

LRA Auto-Resonance



DRV2603 upgrade your LRA

Benefits of Auto-Resonance Detection

Better Actuator Braking performance

Braking is important for creating “sharp” and “crisp” haptics effects as well as “event separation” for multiple-event waveforms like double-clicks.

2x More Force

when driving the linear resonant actuator at resonance

50% Less Power

when driving haptics events like clicks/alerts when compared to drivers with no automatic resonance detection

Simplified Input Signaling

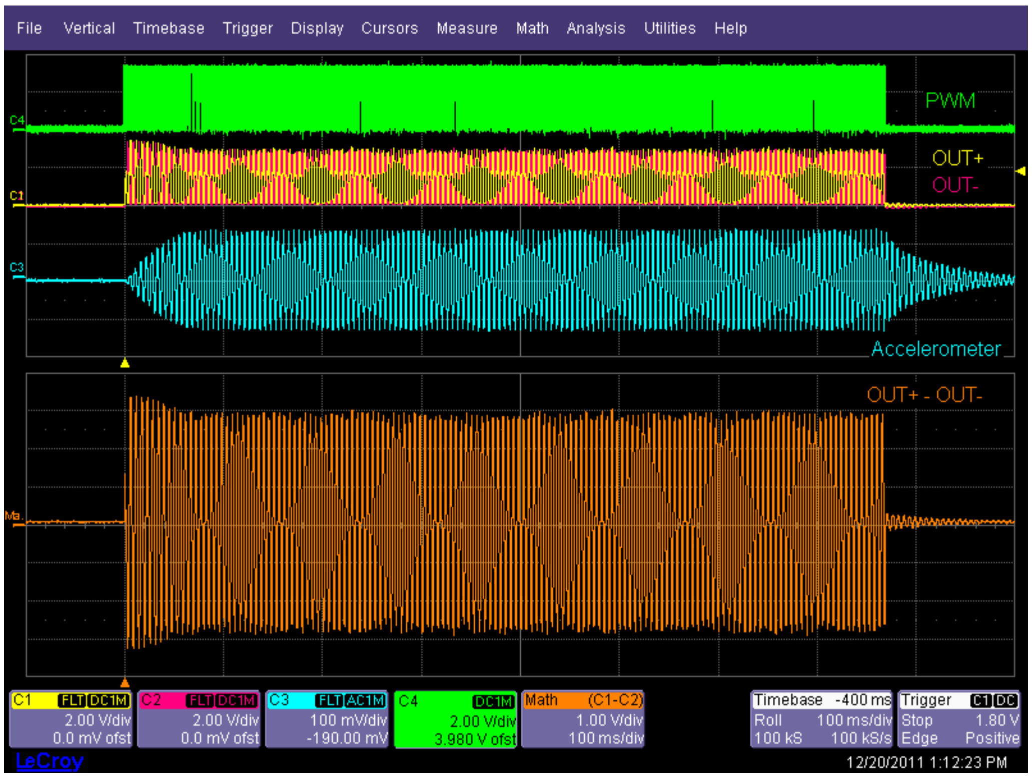
No specific input frequency required.
Accepts PWM signals from 10kHz – 250kHz

Small Solution Size

requires only one bypass capacitor

DRV2603 Double LRA effects

- The DRV2603 is able to detect and drive the actuator at the resonant frequency, producing more force.
- For this actuator, the resonant frequency shifts up when driven hard. The DRV2603 tracks the frequency shift with amplitude.
- Auto-resonance will provide consistent force across various effects.



Test Device = DRV2603

PWM Input Freq = 22.144 kHz

PWM Modulation = DC Voltage

Output Frequency = 191 Hz

Output Vrms = 2.014 Vrms

LRA Resonant Freq = 175 Hz

Acceleration = ***2.46 g***

2X

More Force

DRV2603 Increase LRA Efficiency

- **Current Consumption** – current consumption per "*g*" of acceleration
  - "mA/*g*" is used to measure the efficiency of an actuator
  - If the drive frequency is not at the resonant frequency the actuator will consume more current per "*g*" of acceleration
  - DRV2603 Auto-resonance Benefits:
    - Power savings with 60% less current consumption per "*g*" by driving at the resonance frequency

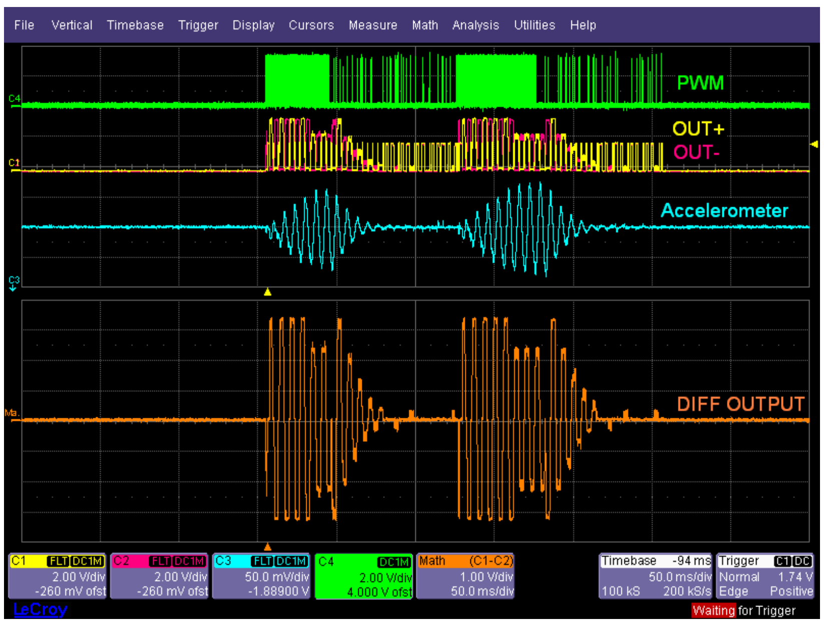
	Average Current Consumption	Acceleration	Normalized Current
DRV8601 with LRA – no Auto Resonance tracking	76.9 mA	1.175 *g*	**65.42 mA/*g***
DRV2603 with LRA – Auto Resonance tracking enabled	64.8 mA	2.46 *g*	**26.38 mA/*g***

60%

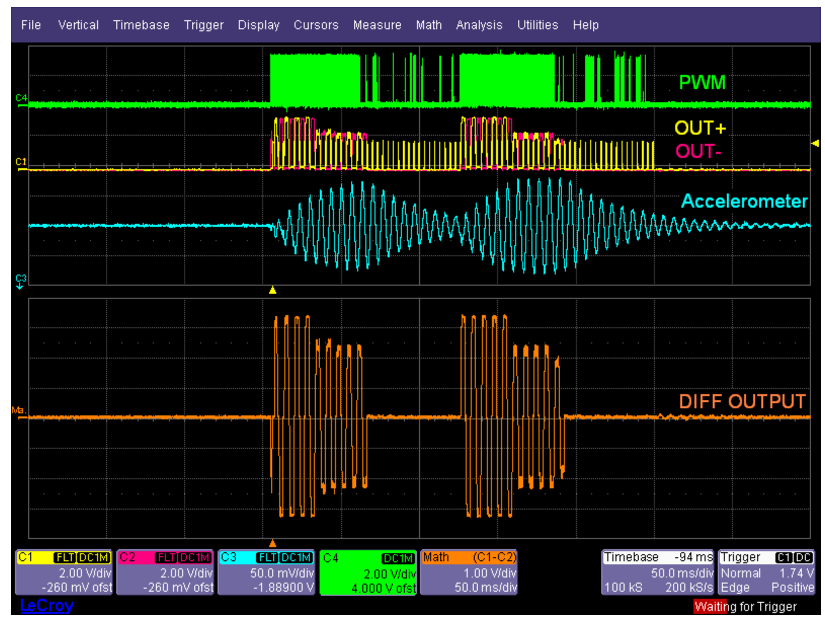
Current Savings per "*g*"

DRV2603 Breaks LRA Sharply!

- **Braking –** stopping the actuator quickly to create “crisp” effects
  - LRA braking is only possible when a signal exactly 180° out-of phase is applied to the actuator at the exact resonant frequency
  - DRV2603 Auto-resonance Benefits:
    - The DRV2603 detects the exact resonant frequency
    - Will automatically reverse drive the actuator exactly 180° out of phase.



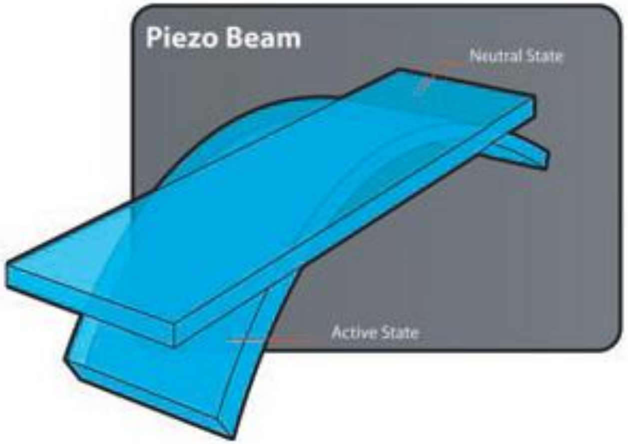
Braking



No Braking

Piezo Motor

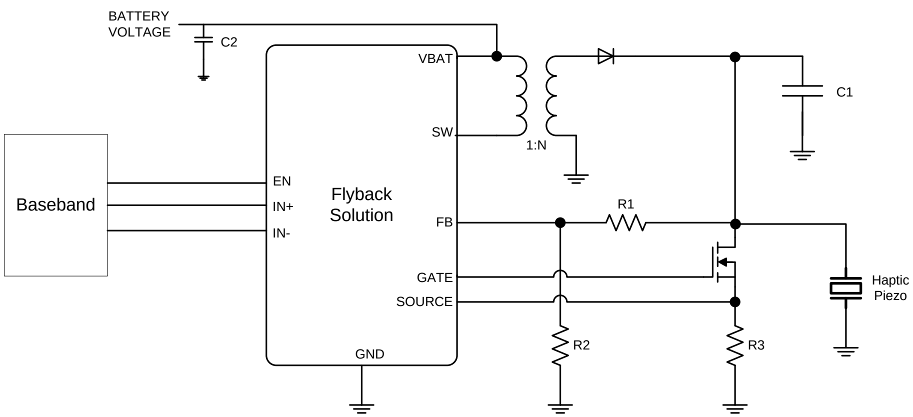
- When a voltage is applied, piezo-electric material will quickly move some distance
- Precision actuation for **high-definition** haptics
- Creates vibrations by **attaching directly to the screen** or by using a mass, either "localized" or "whole-body" vibration
- Small size, thickness varies between 0.5mm and 3mm
- No magnetic fields
- Response time of **less than 1ms**



Voltage	50 – 200 V_{pp}
Power	7% of battery
Frequency	1-300Hz
Response	< 1 ms
Waveform	Sine wave
Vendors	AAC Murata Hokuriku TDK

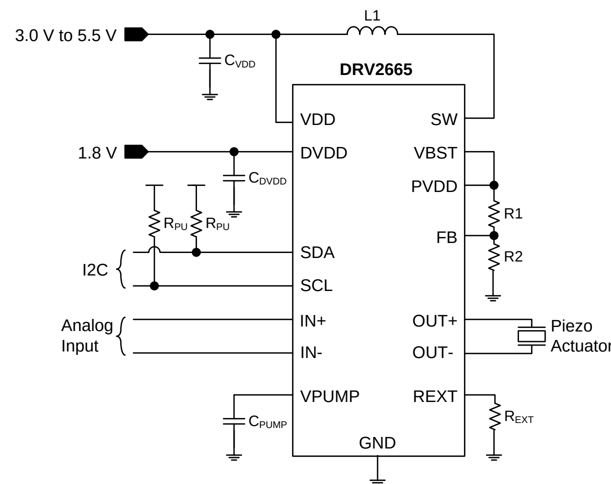
DRV2665 Save Board Space

Traditional Flyback Solution



- Transformer – Bulky, Expensive
- External FET/ Diode
- Difficult charge/discharge control schemes that are separated
- Solution Size ~200mm^2

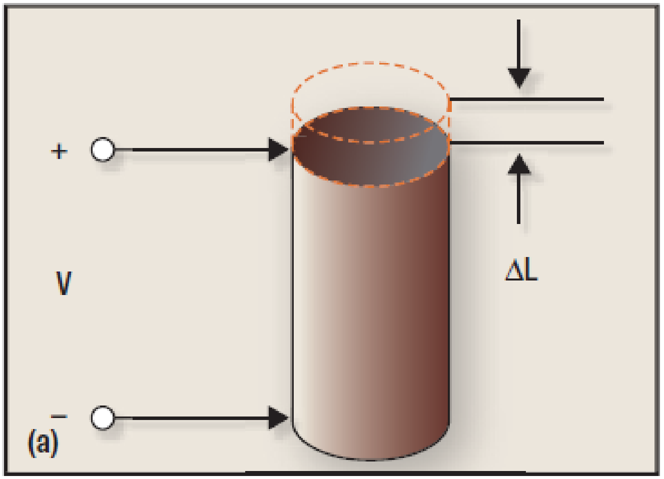
TI's Integrated High-Voltage Process



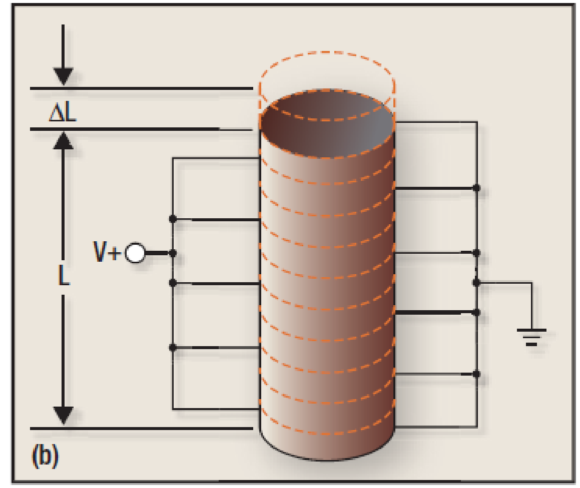
- **Transformer-less**
- **Integrated FET/LDO/DAC/DSP/Timer/Diode**
- Supports streaming I2C touch feedback (Immersion's TS5000 compatible) through a 100-byte FIFO interface
- **Solution Size ~100mm^2**
- Digital/Analog input

Piezo Motor Types

Single Layer



Multi-Layer



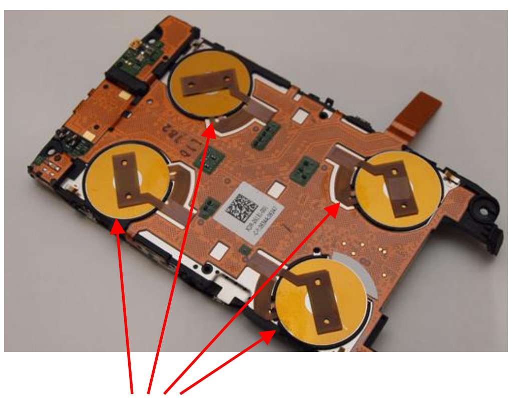
- Single-layer requires up to 200Vp-p (high voltage)
- More cost effective
- Lower capacitance and requires lower current

- Multi-layer requires up to 50Vp-p (lower voltage)
- Cost scales linearly with number of layers
- Higher capacitance and requires higher current

Piezo Motor Form Factor

Piezo Discs

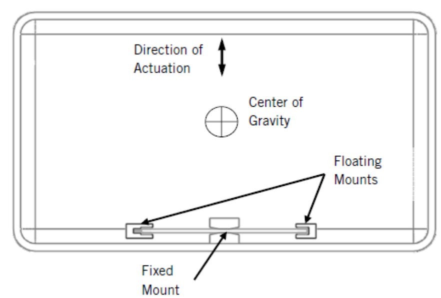
- Must push screen in z-direction
- Requires multiple elements
- Tend to “pop” the screen with a click burst
- The audible sound it makes could be made desirable, but is difficult to make inaudible



4 Piezo Elements

Piezo Strip Bender

- Can be used to vibrate the glass from the side in a lateral direction
- Requires only one element
- Utilizes the mechanical resonance of the glass relative to the rest of the phone mass.
- Gives more vibration for less electrical energy
- A resonant tone can vibrate the glass silently

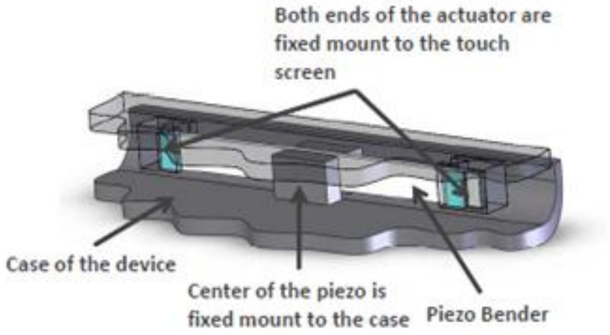


Single Piezo Element

Piezo Motor Form Factor

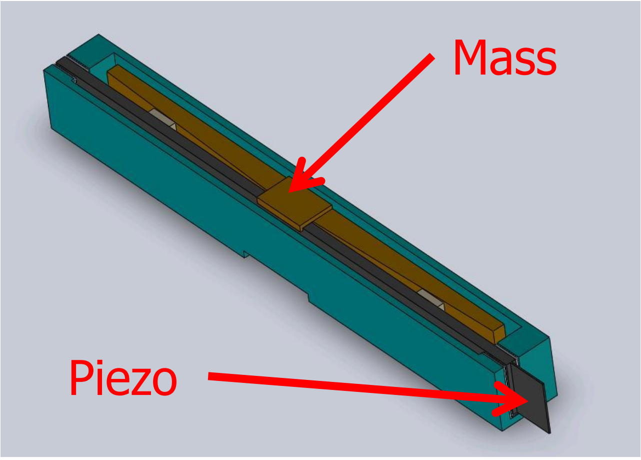
Piezo Bender

- A piezo bender is attached **directly to the screen**
- The piezo bender vibrates a floating or suspended screen for a more "localized" feel
- Requires custom mechanical solution



Piezo Module

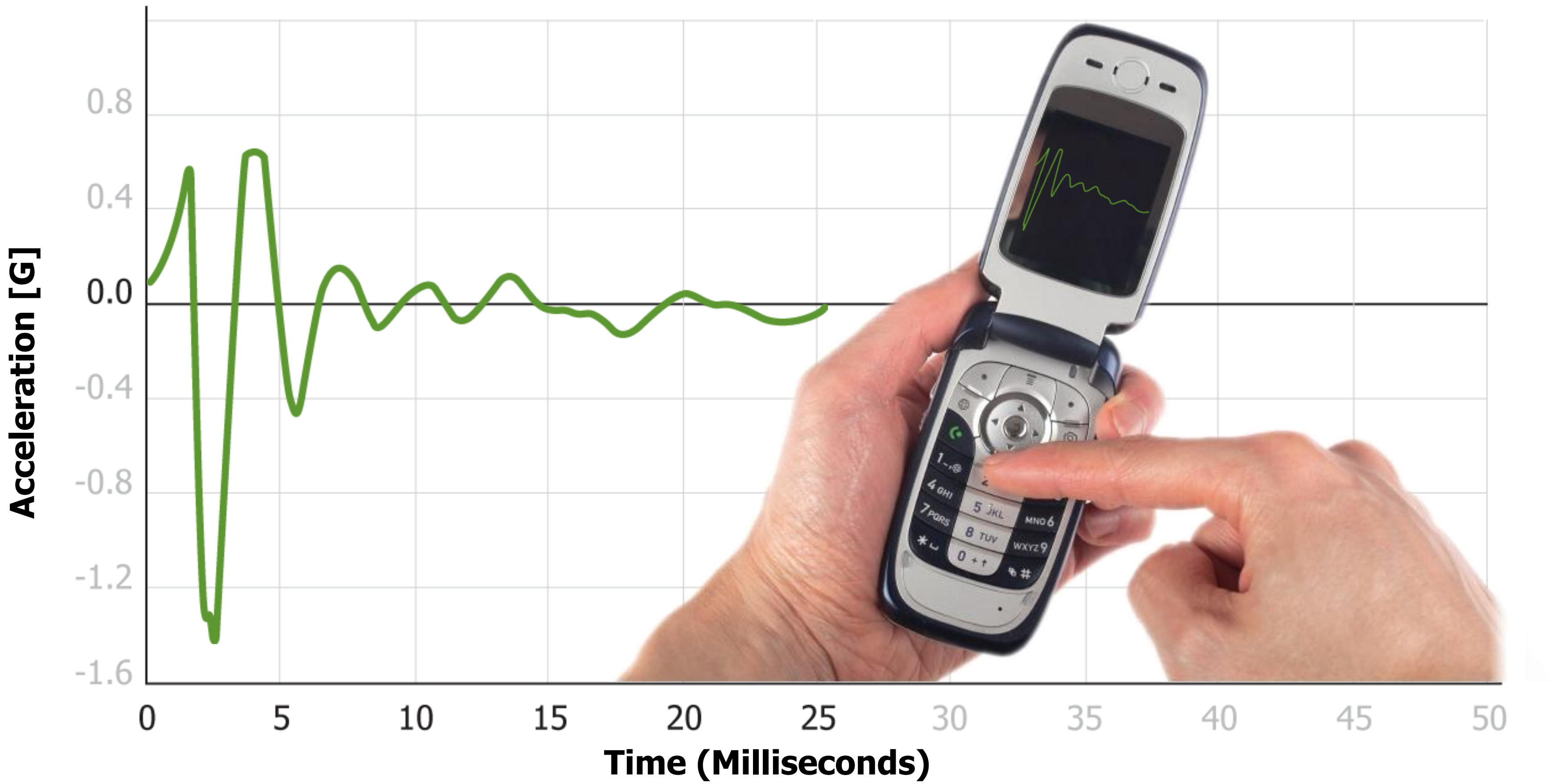
- The module consist of a **piezo bender and mass**
- The module is attached to the device case or PCB and vibrates the "whole device"
- Best **drop-in solution**



Bandwidth: Key Press Profile

The graph below represents the acceleration of a mechanical button

Haptics Strength – measured in Acceleration (G - m/s^2)



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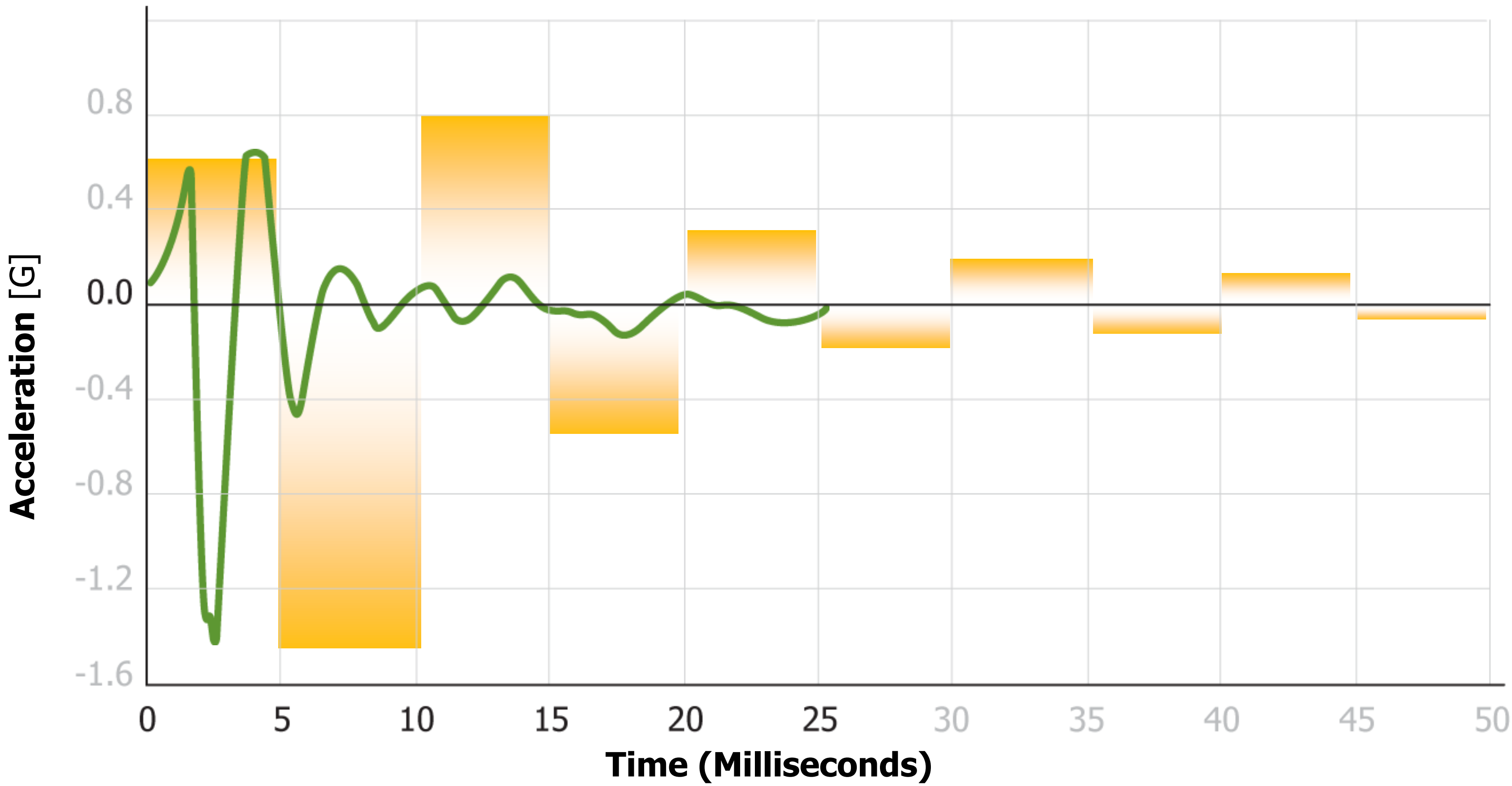
Bandwidth: ERM Touch Feedback Effect (Key Press)

Compare the ERM response to the mechanical button

Haptics Strength – measured in Acceleration (G - m/s²)



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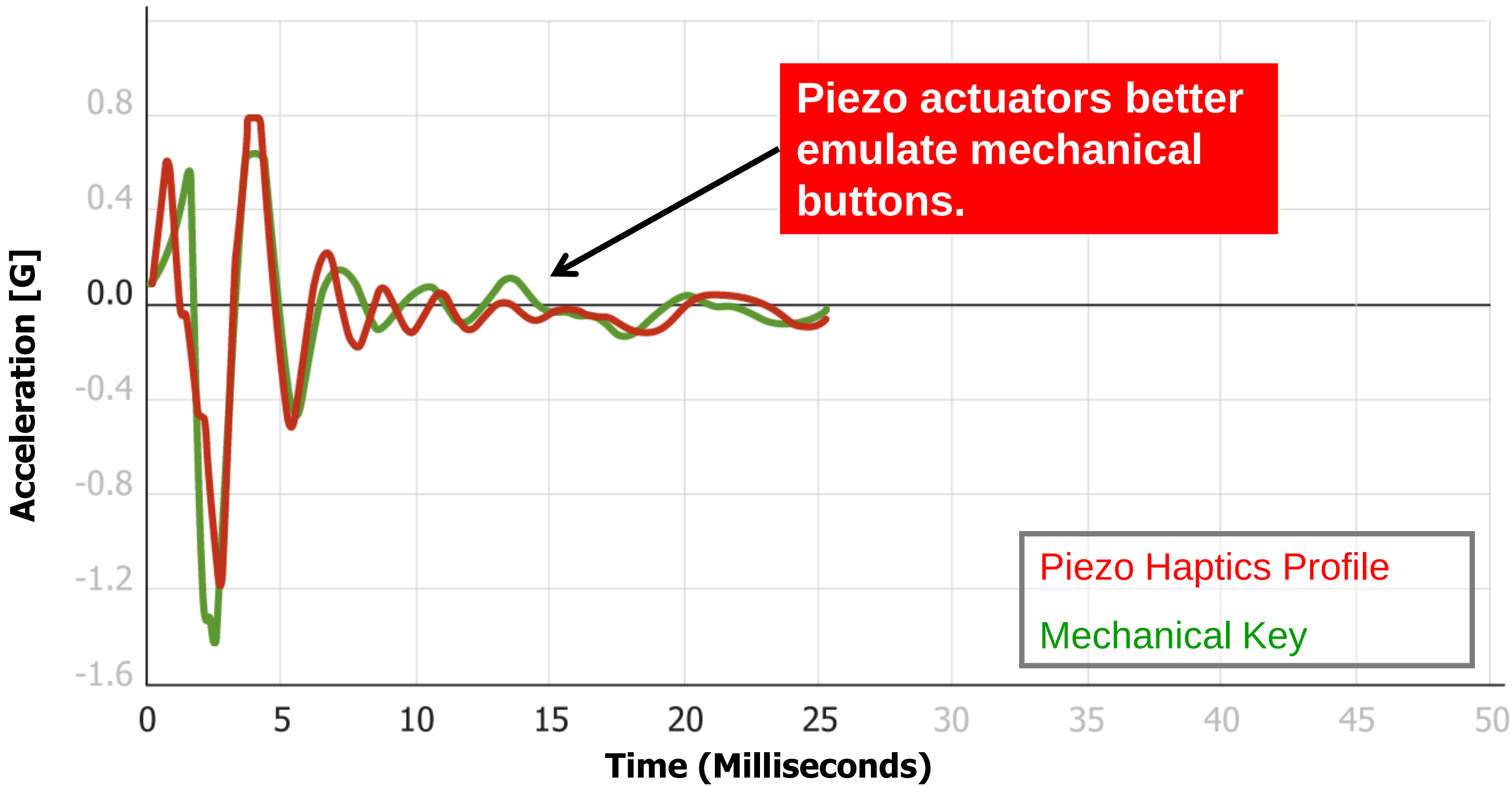
Bandwidth: Piezo Touch Feedback Effect (Key Press)

Now compare the response of the Piezo actuator and the mechanical button

Haptics Strength – measured in Acceleration (G - m/s²)



TI Confidential – NDA Restrictions

TI Success Driving Touch Feedback

htc
quietly brilliant

SAMSUNG

NOKIA

LG

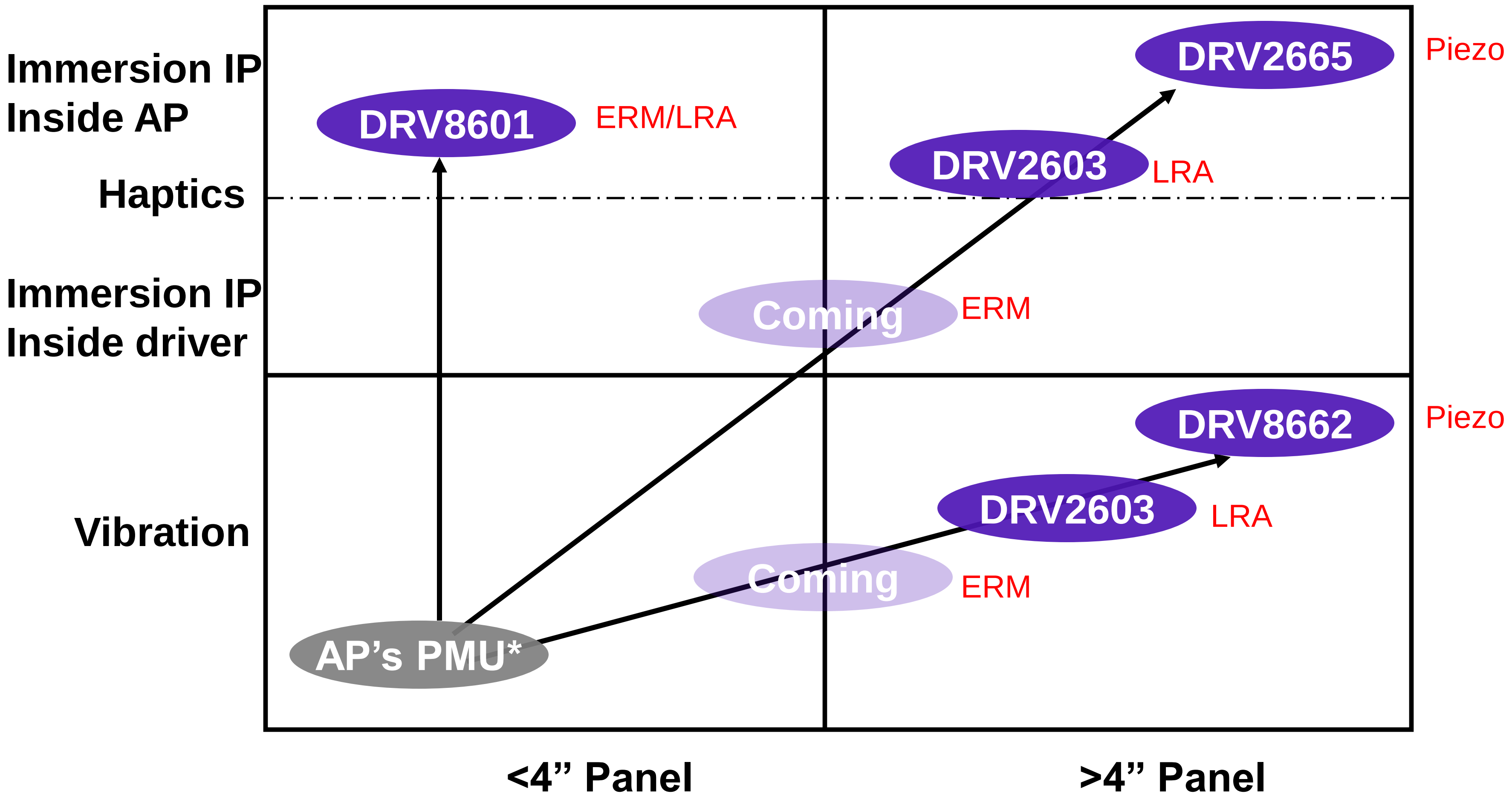
TOSHIBA

BEST BUY

PANTECH

hp

Solutions Comparison from vibration to haptics



*Application processor (AP) platform got PMU companion chip. The PMU integrates LRA or one way ERM driver usually. As PMU miss auto-resonate detect feature, it got weak vibration in large size smart phone due to heavy weight. As one way ERM driver miss the breaking feature, user miss the perception of double click feels or complicated vibration effects.

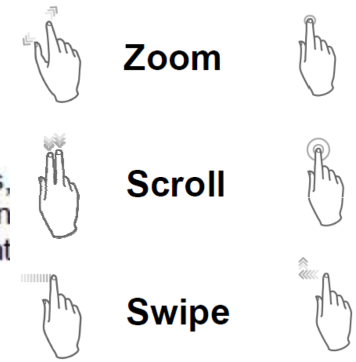
Moving Next Driving Ultrabook & Accessories

Haptics for Windows 8 touch screen

Haptics enabled media buttons

Haptics enabled keyboard

Touchpad gestures, Left & Right button replacement



Zoom

Tap

Scroll

Long Press

Swipe

Advanced

Accessories

Haptics enabled scroll wheel or touch surface

Haptics enabled media buttons

Moving Next Driving DSC

- Camera touch screens
- Warnings such as flash off or incorrect sensitivity selected
- Self portrait indicator – did it take my picture?
- Lens cleaner

Moving Next Driving Home Appliance

- **Remotes** with static or dynamic controls
  - Audio/Video
- **Appliances**
  - Ovens
  - Washer/Dryer
- **Home Systems**
  - Alarm
  - HVAC

Moving Next Driving Automotives Applications

There are 4 primary use-cases for Haptics in automotive.

Touch-Screen Center Console	Track-Pad	Lane departure Warning	Switch and Knob replacement

More Applications Booming

Mobile Phones & Tablets

- Virtual Keyboard
- Gaming
- Personalized Alerts
- Audio & Video

1.2B HANDSETS

Consumer

- Personal Computer
- Navigation Devices
- Personal Media Player
- Home Automation
- Camera
- Printer

400M DEVICES

Commercial / Industrial

- Point-of-Sale
- Kiosk
- Desktop Phone
- Data Terminals
- Industrial Control
- ATMs

100M DEVICES

White Goods

- Washer / Dryer
- Microwave
- Oven
- Security
- HVAC

Gaming

- Controllers
- Gaming Accessories
- Handhelds
- Arcade / Casino

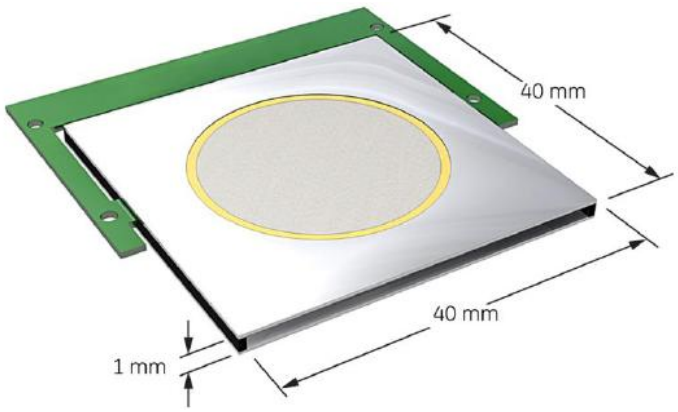
70M DEVICES

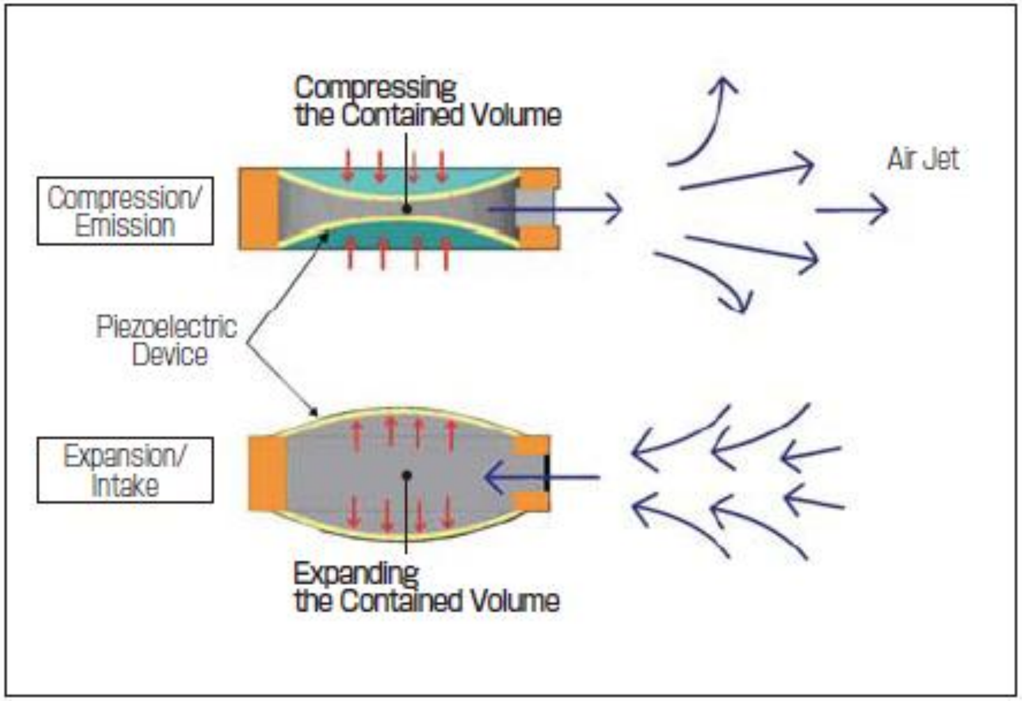
Other

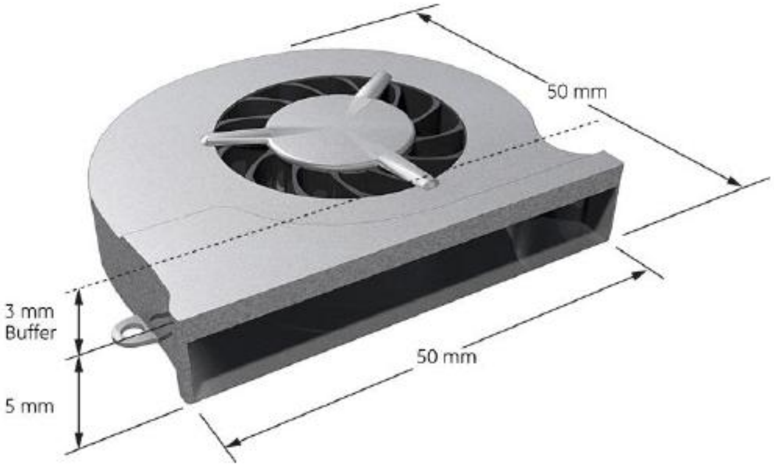
- Automotive
- Medical
- New Technologies

Piezo Cooling Fan

Piezo Cooler slim height

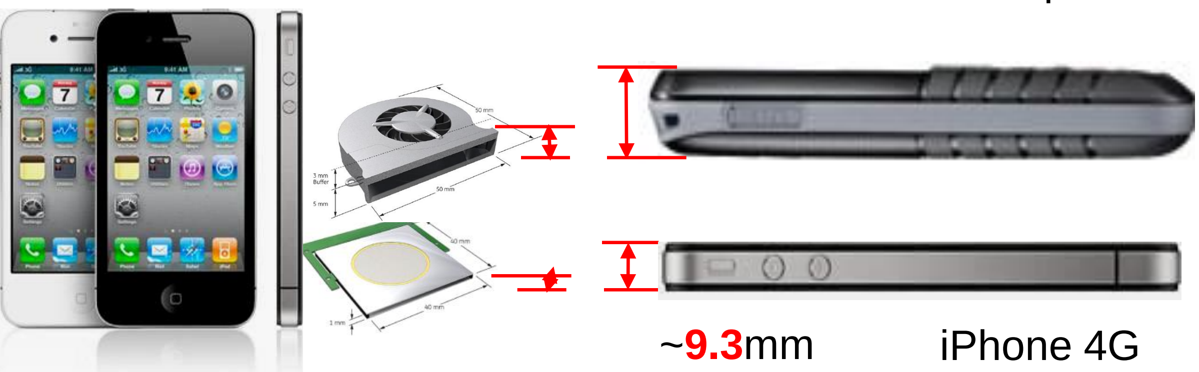






Market Trend More slim EE, more thermal challenge

Old Smartphone



~**9.3**mm iPhone 4G

HTC One X overheat up to 63.8 °C

Notebook

Base Thickness~**12**mm Apple MacBook Air

Why Consider Piezo ?

$ **Low cost**

- Made of inexpensive ceramic
- No rotary parts (i.e. no bearings)
- Simple circuitry

W dB **Low power & Low noise**

- Power Consumption < x10 vs. conv.
- Efficiency conversion > 99%
- Operate at < 100 Hz

°C/W Life **Performance & Reliability**

- Can cool low power components
- Accommodate low z-height
- Preliminary reliability promising

DRV8662 & Roadmap

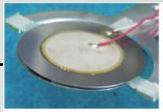
**Sample Spec are subject to change w/o notification

Piezo

In definition
**Samples Now

Coming

- 120 VAC SL Piezo Driver
- Integrated Digital Front End
- Oscillation frequency adjustable



w/ Digital Front End Integration

M/P - Now

DRV8662

- 200 Vp-p SL Piezo Driver

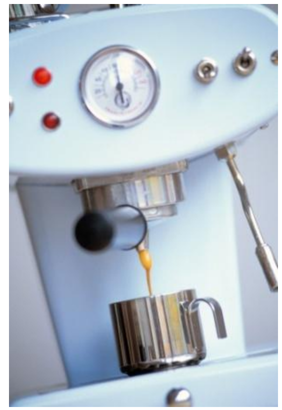
Yt2012

Yr2013

Actuators

Where are Actuators used?

Driving Solenoid Valves



In irrigation, in white goods ...

Driving Safety Relays

In vehicles, in (solar) inverters ...

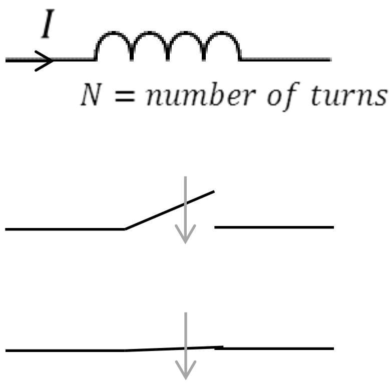
Driving Inductive Actuators

In magnetic contactors

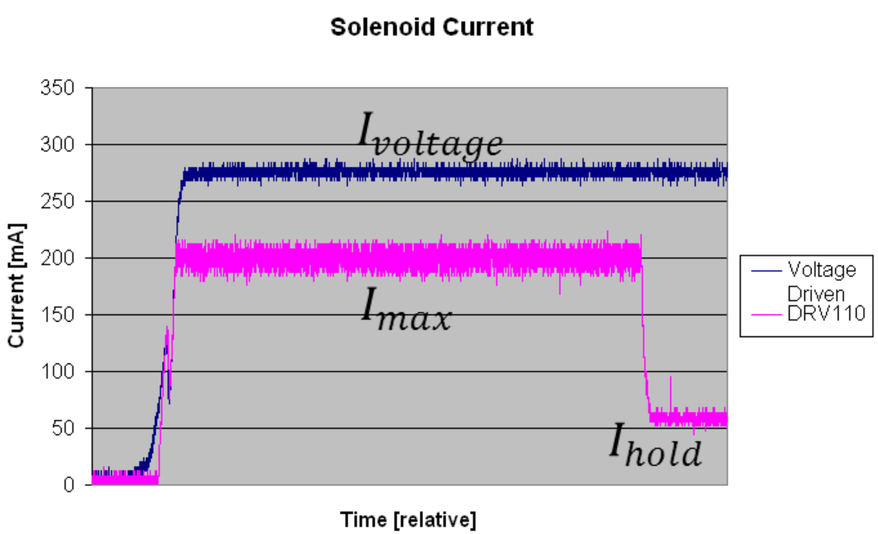
In force feedback

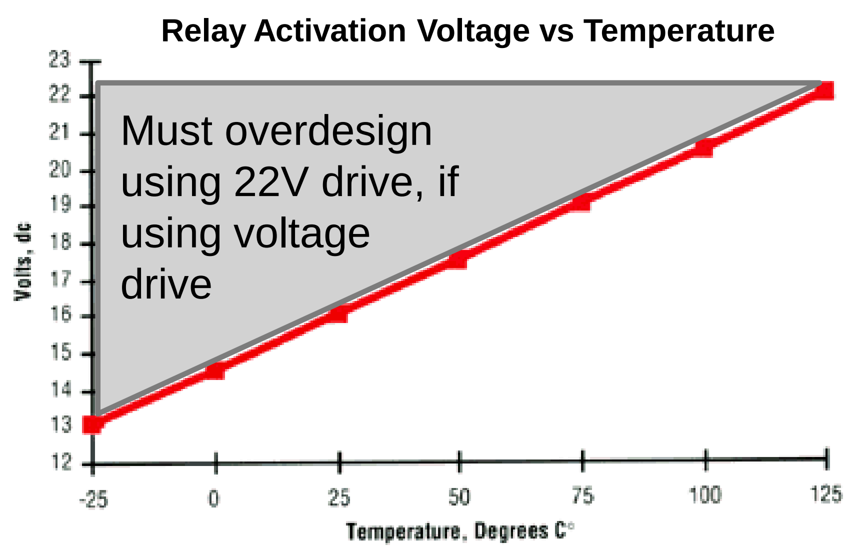
Current Drive vs Voltage Drive

$$F_{em} = N \times I$$



- Electromagnetic force of a solenoid is directly related to the current, so current drive is optimal for relays, valves etc.
- Voltage drive forces overdesign, as current $I_{voltage}$ will vary with coil resistance, temperature, supply voltage variations …
- Closing a relay or valve requires a lot of energy. The current I_{max} to activate a solenoid actuator can be high
- Holding a relay or valve closed requires significantly less energy than closing. Thus: I_{hold} << I_{max}





DRV110 – Optimal technology for driving relays & valves

Calendar

In Production!

The product:

a) Current controlled solenoid driver

b) Closed loop PWM regulates the current

c) Supply voltage: 6-500VAC rectified

d) Programmable pull-in time and current, programmable hold current

e) Gate voltage: 15V, down to 5V

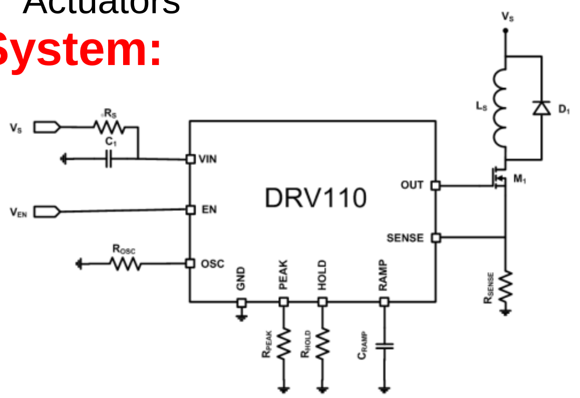
f) MOSFET gate drive current: 10mA

g) Programmable switching frequency

Applications:

- Solenoid Valves, Relays and Actuators

System:



Benefits:

a) EM Force directly proportional to current: optimal (energy, control) way of controlling relays/valves

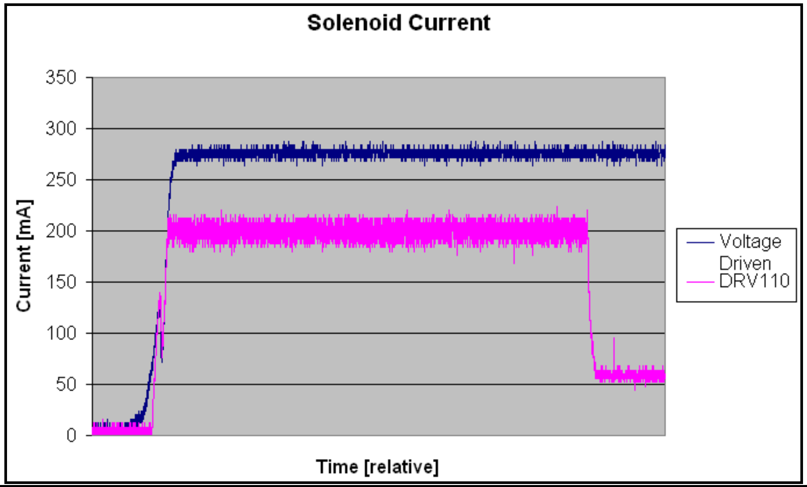
b) Actuator force will stay constant regardless of supply and component variations. Enables optimizing the system.

c) Internal clamping regulator enables wide Vsupply

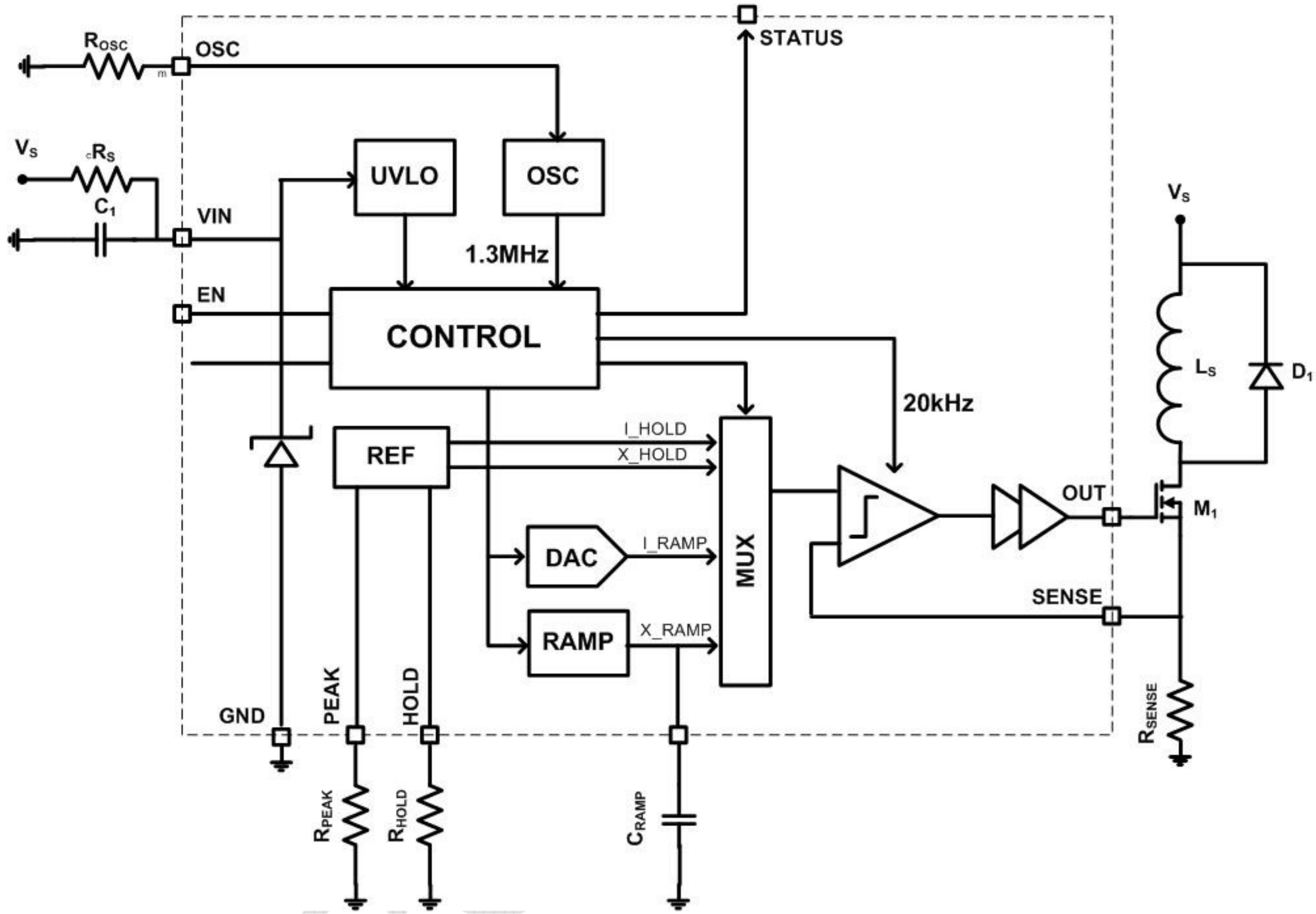
d) Optimal, fixed current enables power minimum pull-in and hold operation

e) Higher gate drive voltage enables use of low cost MOSFET

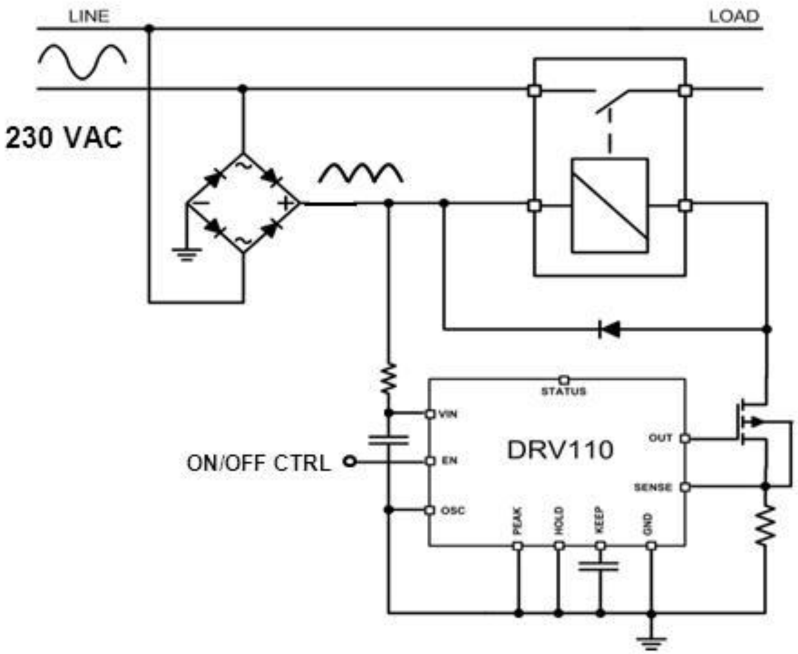
Purple line represents DRV110 current regulation behavior. Area above purple line represents energy wasted by traditional open loop voltage drive, depicted by the blue line

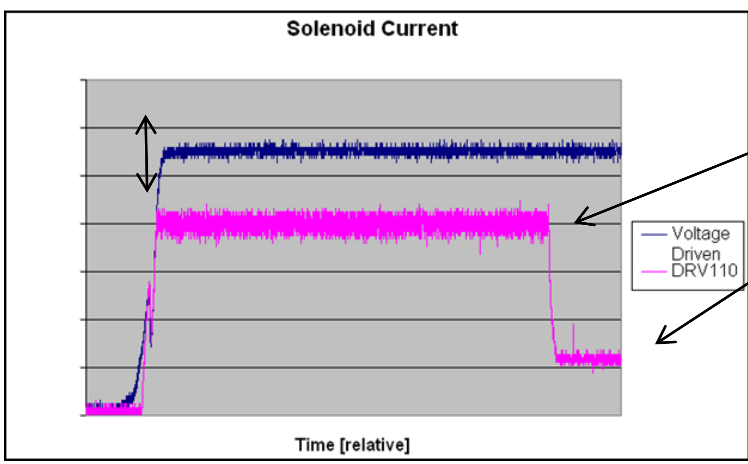


DRV110 – Detailed View



TI Success In Magnetic Contactors





Magnetic contactor:

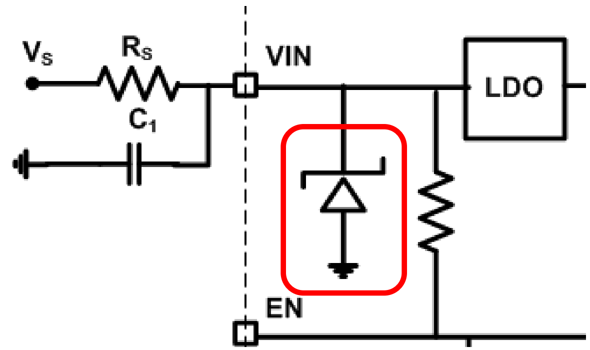
- **Operates as an automatic circuit breaker**
  - Control signal may be: under voltage, over voltage or power level (ON/OFF CTRL in the picture)
- **Reliability is a challenge**
  - Supply voltage can be the line, while the current needed to launch the solenoid actuator can be in range of Amperes → Thermal stress!

Single chip solution with DRV110:

- **Power dissipation optimized**
  - Due to current control, no margin needed for the change caused by temperature or solenoid resistance variation, as in voltage driven case (blue line)
  - Separate value for launch current, which may need to be in range of Amperes (purple line)
  - And separate value for the steady state hold current, which may be only 1/20 of the launch current value
- **DRV110 supply connected to rectified mains**
  - Shunt regulator of the DRV110 keeps the VIN supply voltage in right range (~15V)
- **Solenoid connected to rectified mains**
  - Closed loop PWM control keeps the solenoid current constant regardless of supply voltage changes

Input Voltage Regulation in DRV110

- Integrated Zener, i.e. shunt regulator, in DRV110 makes it possible to connect the VIN pin through R_S for example to AC mains
  - As long as VIN pin is <15V, the shunt regulator is not active and the quiescent current is ~360uA (typ) when EN=1 and ~200uA (typ) for EN=0
  - If VIN pin voltage tries to rise above 15V, the shunt regulator starts to sink current
  - It can sink up to 3mA



- To keep quiescent current less than 1mA can be calculated by equation:

$$R_S = \frac{V_{S,\max DC} - 15V}{1mA + I_{Gate,AVE}}$$

  - The average gate charging current is typically low, some tens of uA
  - R_S can be dimensioned such that quiescent current remains just slightly over 360uA (just replace the 1mA value in the equation)

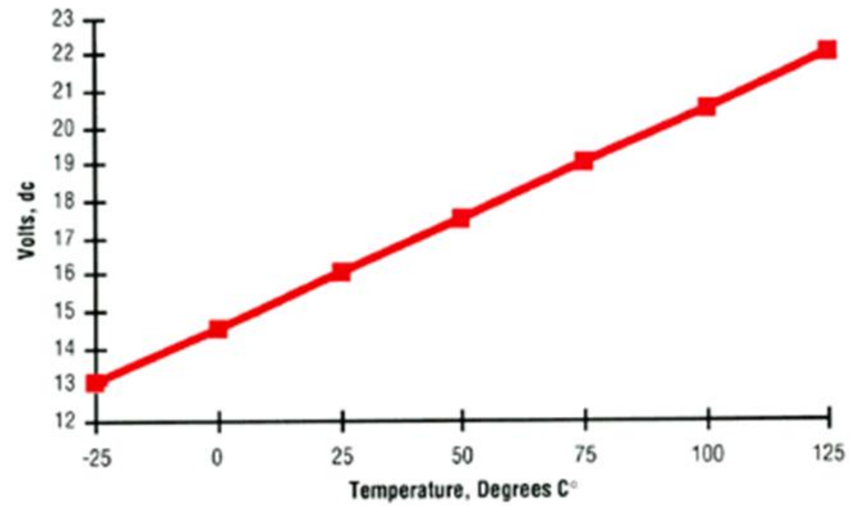
TI Success In Solar Inverter

3.6kW Inverter, 99% efficiency, breakdown of consumed power

Control circuitry	7-8W
Relay consumption, single phase	2W
Relay consumption, three phase	6W
Power stage + Auxillary power losses	15-20W
TOTAL (1% of 3.6kW)	36W

DRV110 solve these issues.

Customer is already using uC IO to do PWM or scaling hold voltage …



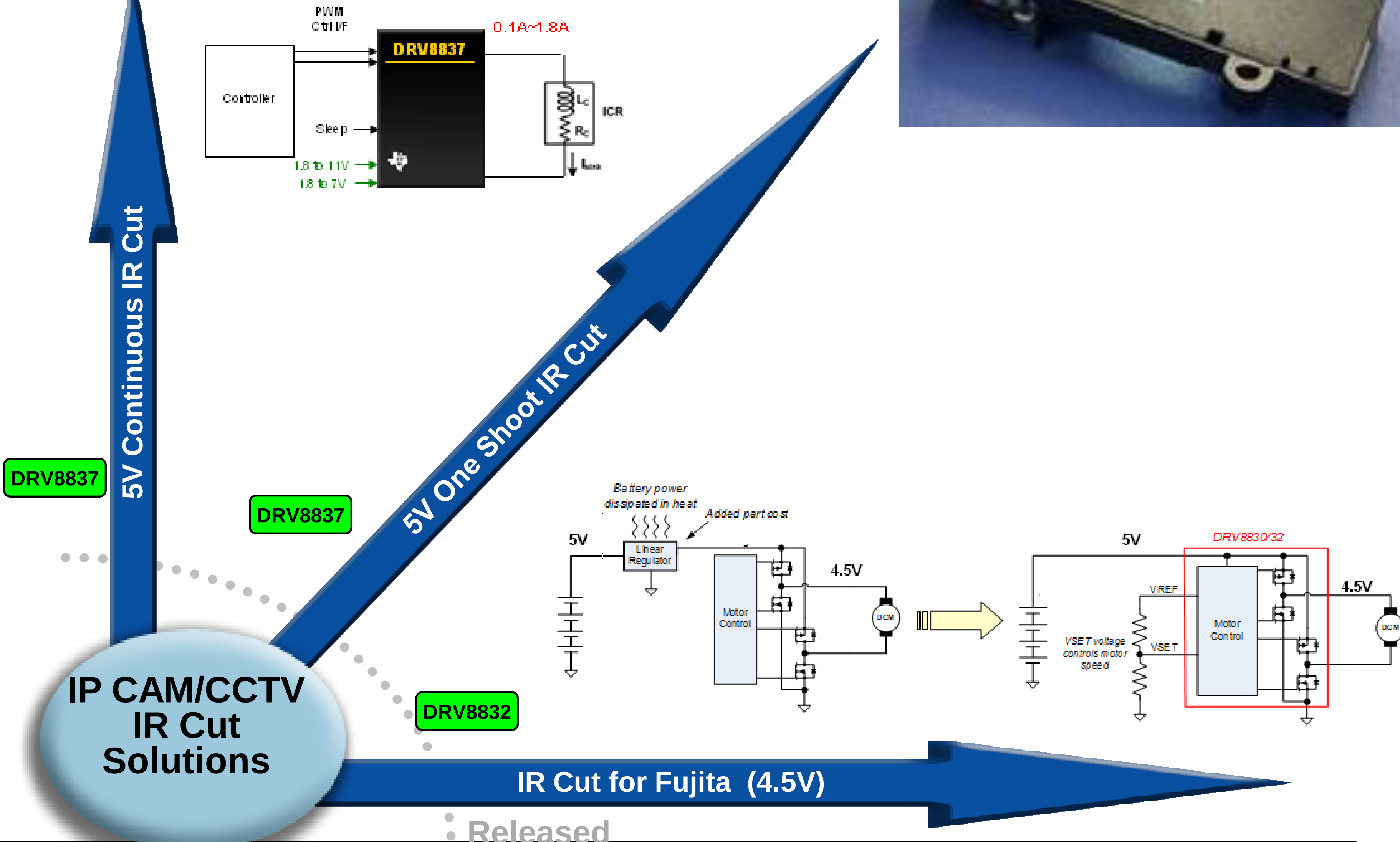
Voltage control does not adjust to temperature change

- 24V relay activation voltage (above)
- 22.5V at 125C, 16V at 25C

Voltage control does not compensate for any system variances

- Supply line, component variations

TI Success In IR Cut

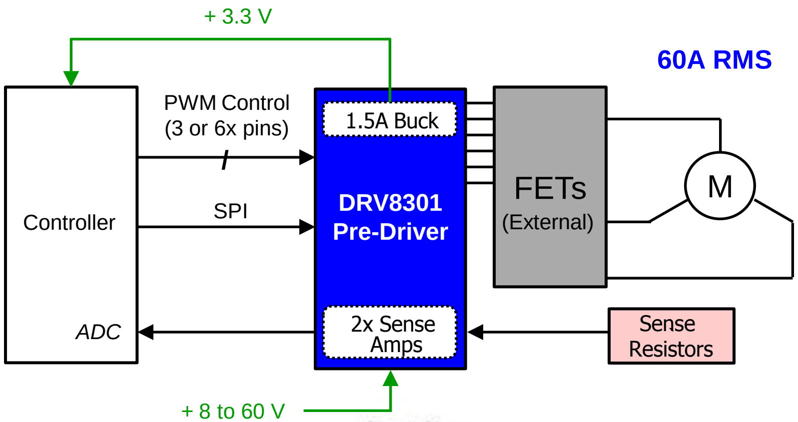


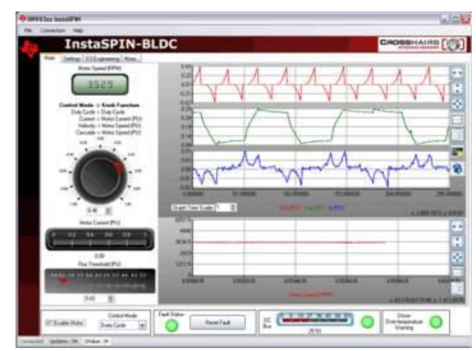
BLDC, DC motor & Stepper

TI Success Driving BLDC motor

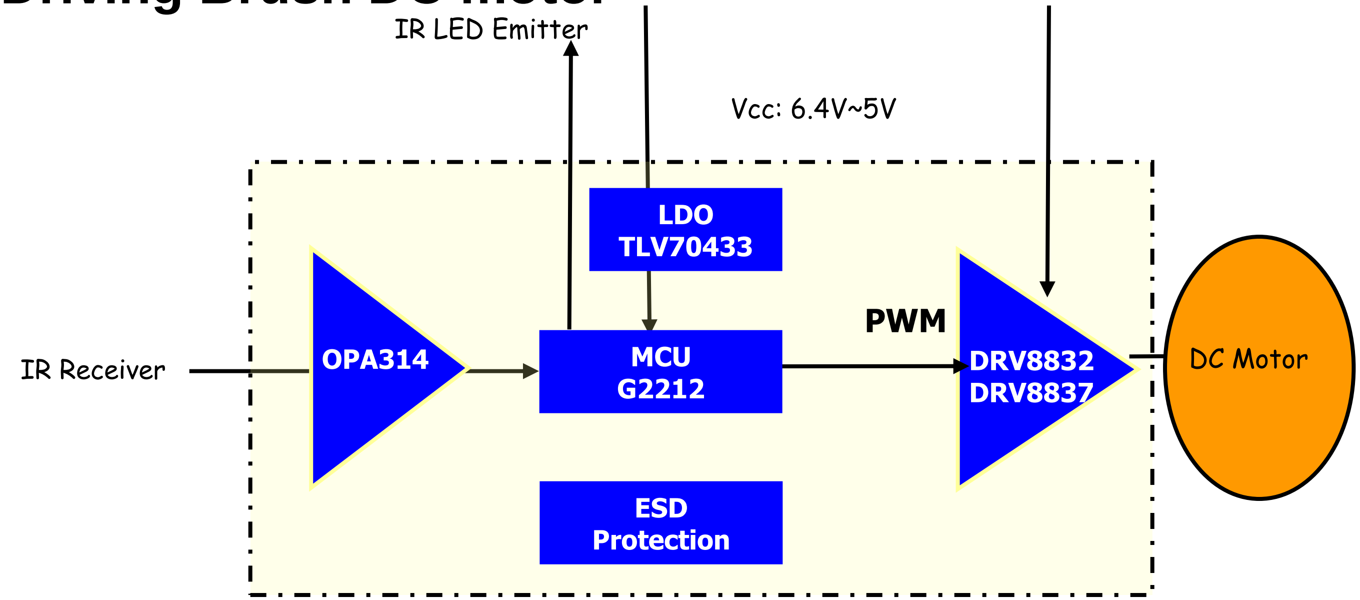
In Stock / In Production
Order Now!

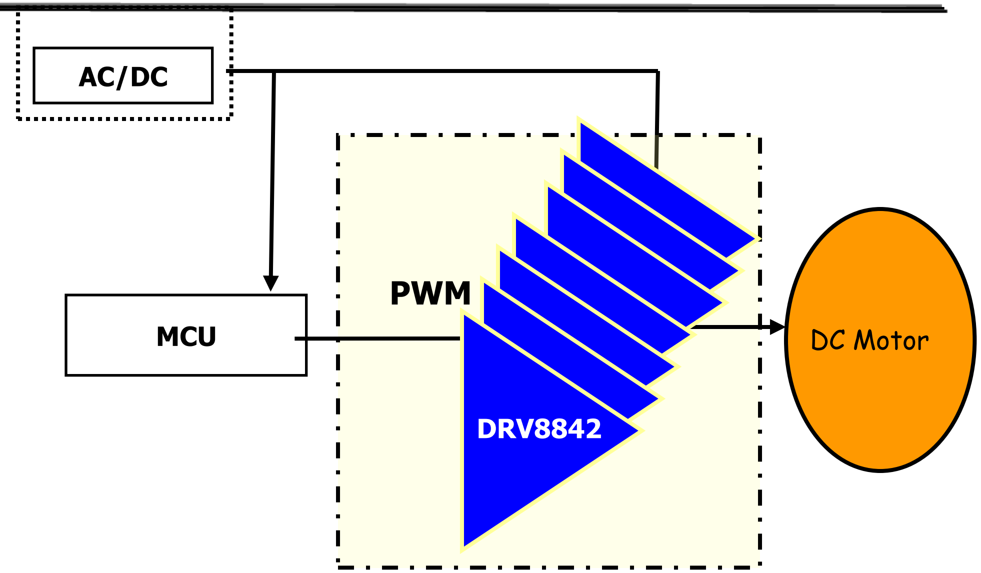
Pricing: $299





TI Success Driving Brush DC motor





TI Success Driving Brush DC motor

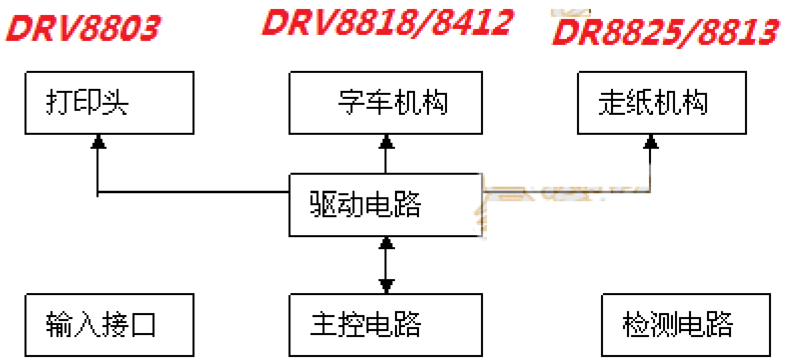
DRV8841,DRV8821,DRV8812
光斑和色彩切片的投放

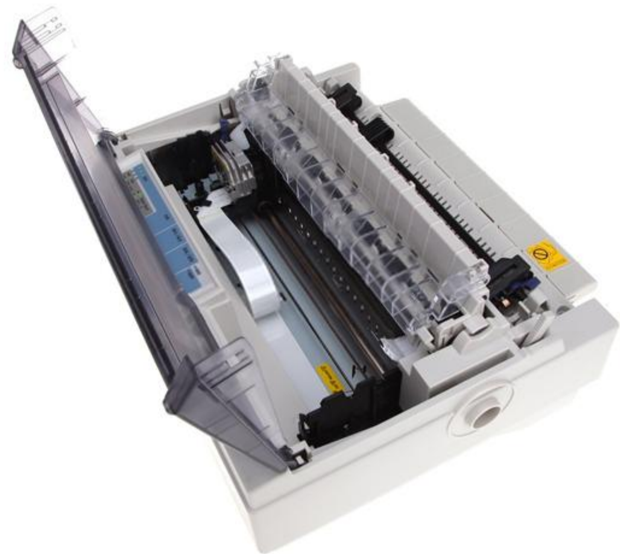
DRV8821=2*DRV8812
DRV8812>L6219&2916

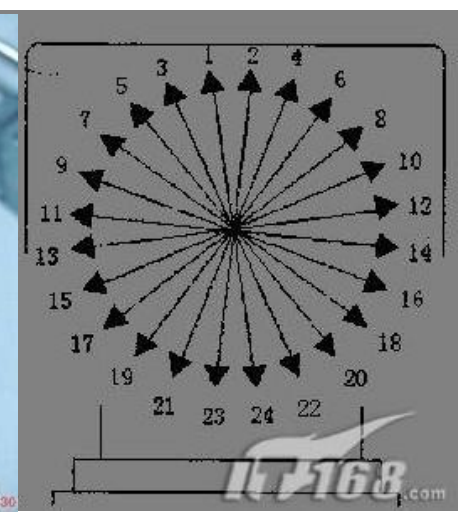
DRV8412*2 X-Y轴的驱动

3A 连续电流、6A 峰值电流

TI Success Driving Stepping Motor





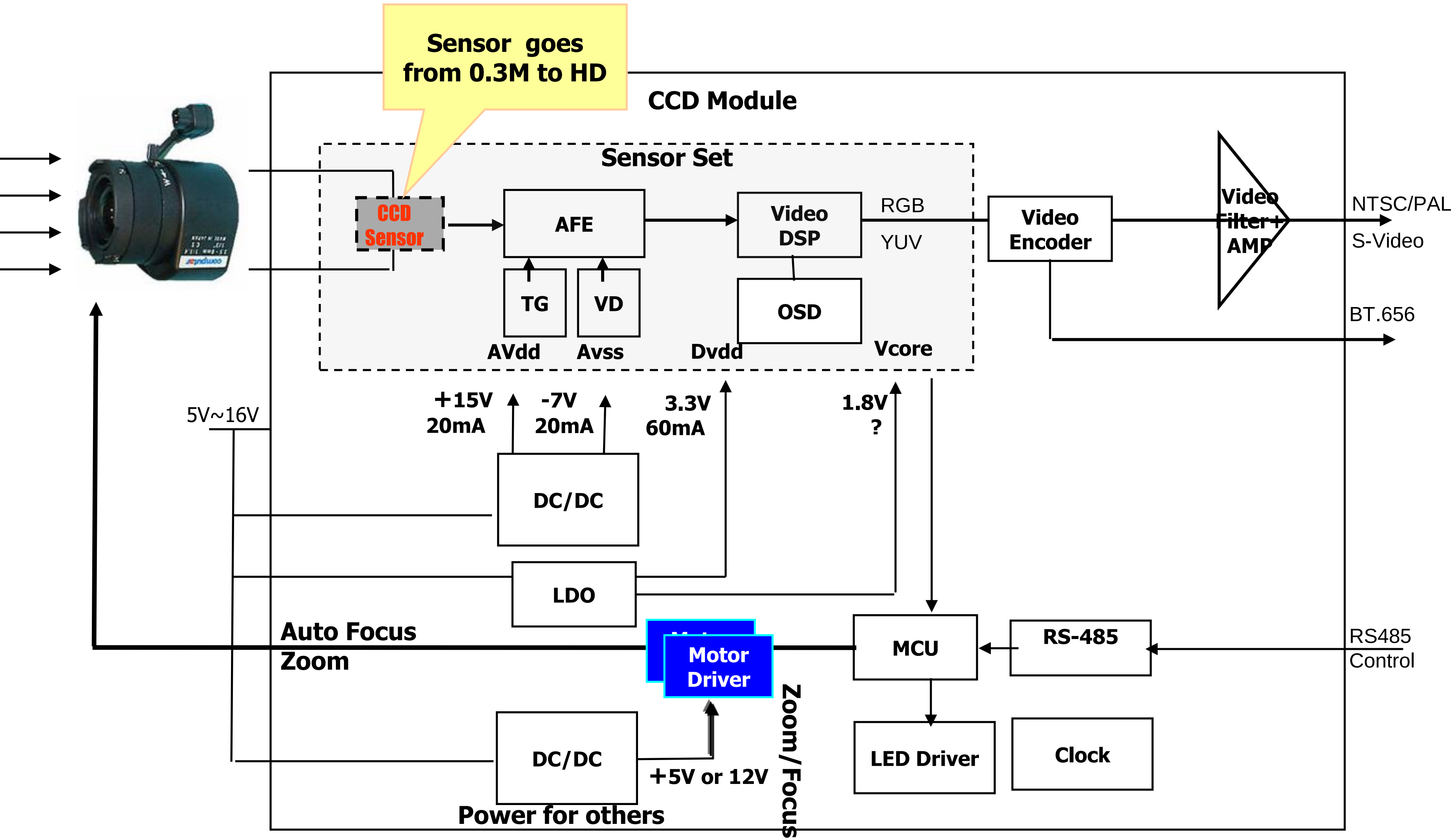


TI Success Driving Stepping Motor

DRV8812/13*3 for Dome& Light Duty PTZ

DRV8829*2 for High load PTZ

TI Success Driving Stepping Motor



Texas Instruments

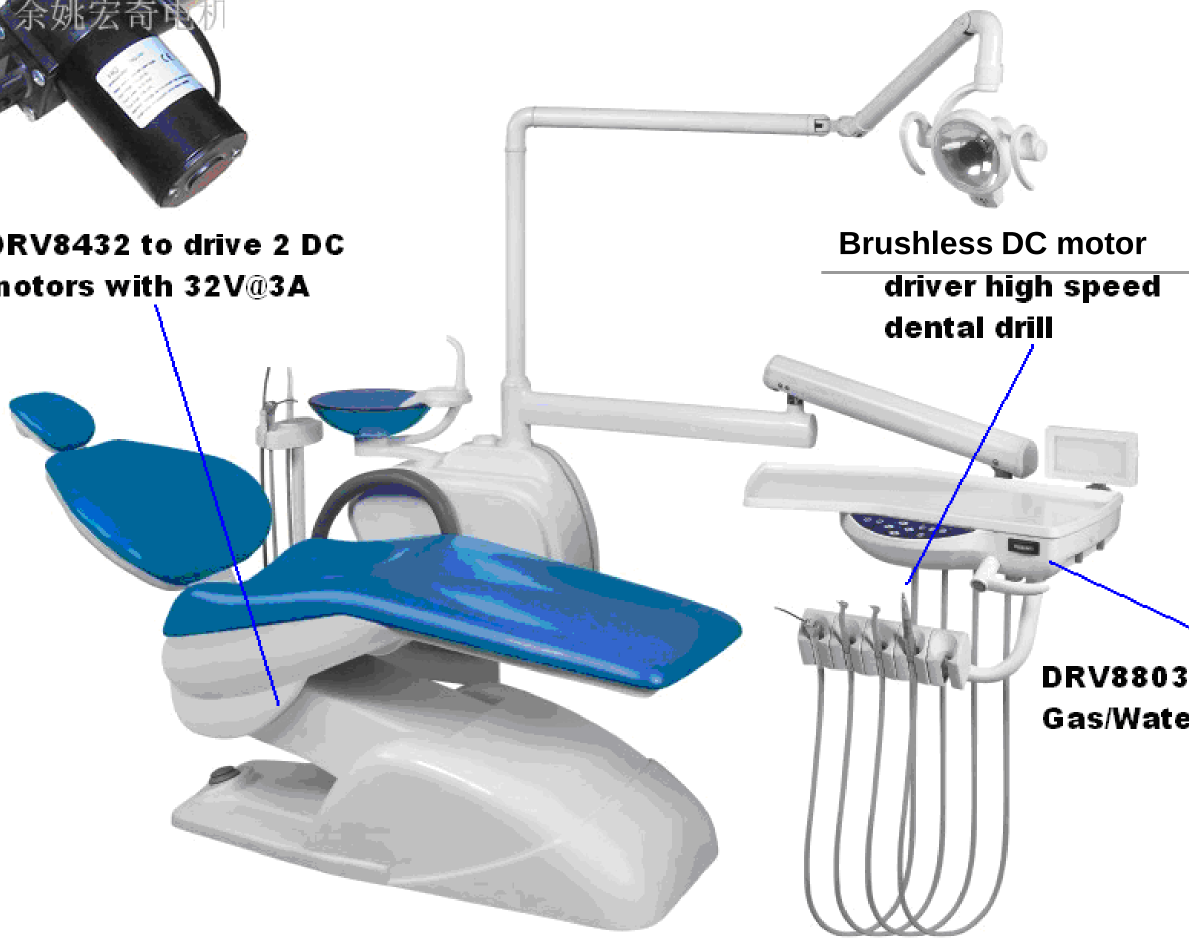
TI Success Driving multi-type motor in one system…

2pcs of HQE Motors

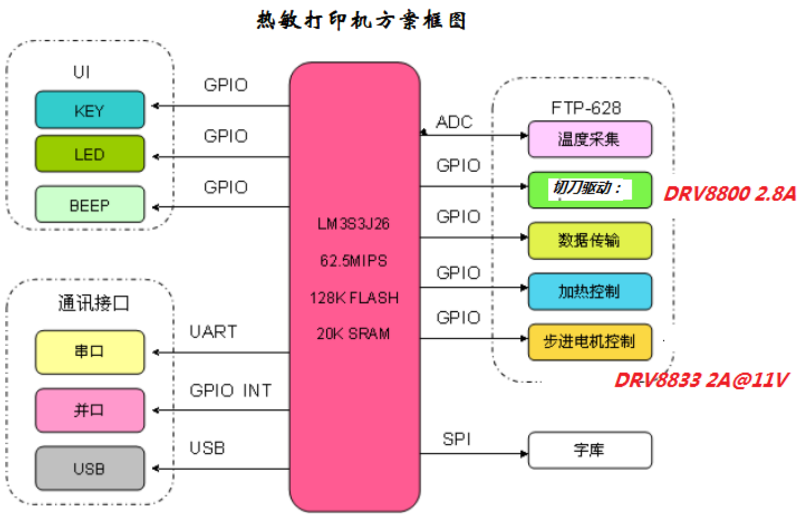
DRV8432 to drive 2 DC motors with 32V@3A

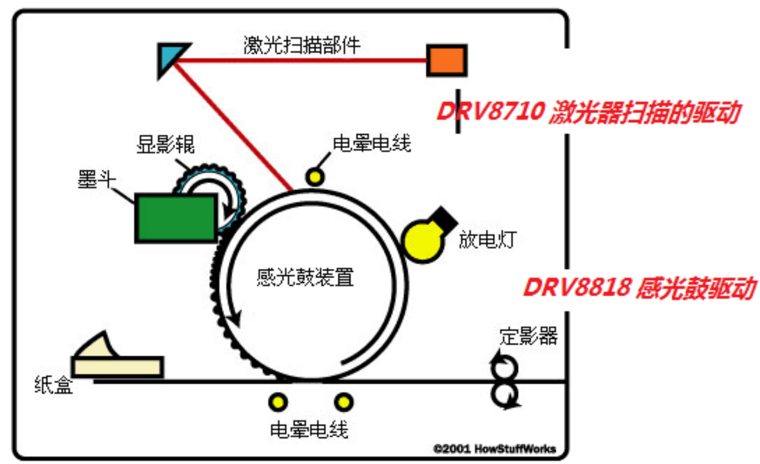
Brushless DC motor driver high speed dental drill

DRV8803 Drive Gas/Water Pump



TI Success Driving multi-type motor in one system…





More details latter on Embedded Processing, DRV88 & fan driver family….