Precision amplifiers

精密运算放大器全系列产品介绍

- 精密运放产品和产品架构介绍
- 新产品的设计和特性介绍
- 锂电池测试仪应用中的明星产品
- 工业自动化&控制系统应用中的明星产品
- 半导体芯片测试仪应用中的明星产品
- TI 官网上现有的资源和工具

TI高精度运放领域架构的分配
从超高性能至性价比优越化的运放产品

Options for Industrial & Auto

Precision Op Amps 高精度运放

- < 1mV Offset
- < 50 MHz BW
- Drift < 2μV/°C
- Industry leading technologies

Instrumentation Amplifiers 仪表放大器

- INAs
- Difference Amps
- PGAs

Power Amps 高功率放大器

- 180V Power Amp
- >200mA Power Amp

Audio Amplifiers 音响放大器

- Class AB
- BurrBrown™
- SoundPlus™
- Audio FDAs

Analog Functions Amplifiers 带模拟功能的运放

- 4-20 mA TXs
- Logarithmic Amps
- Analog Front Ends
- Integ. Gain Switches
- Precision FDAs

AEC-Q100 Amplifiers Automotive 符合汽车业级的运放

- INAs
- Diff Amps
- Op Amps
- Power Amps
- Audio Amps

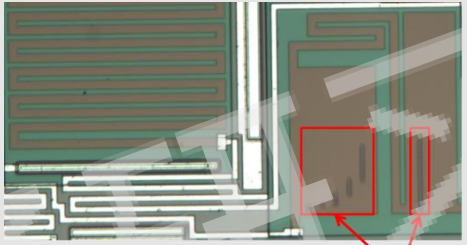
e-trim™ 技术亮点

OPA2205 | OPA2206 | OPA391 | OPA392 | OPA376 | OPA191 | OPA192 | OPA197 | OPA196

技术概要

- 每个放大器是由数十至数千个晶体管、电阻器和电容器组成。 输入失调误差由每个放大器中输入晶体管阻抗的不匹配(或变化）所引起。
- TI 的 e-Trim™ 修整架构可在最终封装製成期间调整内部校正电流源。一旦校准完成便关闭调整电路的关口，因此电路的调整变为永久性而不再受外在因素影响。

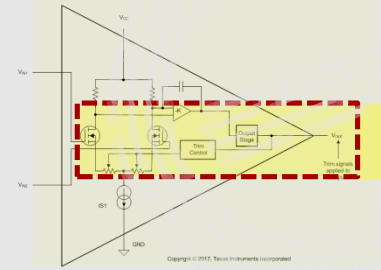
关于激光修整工艺

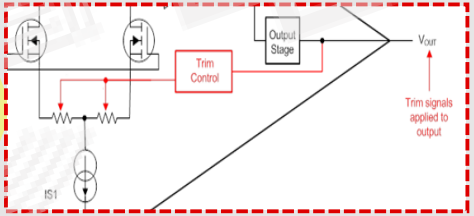


激光修整後的
失调电压和漂移

- 激光修整針對晶圓層在封裝過程前完成電路調整。
- 将整片晶圓切成单独的 die 并封装之后，對其任何物理应力都会導致输入偏移电压和温漂产生誤差。

E-Trim™ 突破哪些技术限制？





- 不 需要额外的引脚或测试焊盘。
- 不 會因封裝過程导致参数变化。
- 效能提升相较于激光修整技术。

Device Example:

Specifications	E-Trim OPA191	Laser Trim OPA140
GBW (MHz) (Typ)	10	11
Input VOffset (µV) (Typ, Max)	5, 25	30,120
Input VOffset Drift(µV/°C) (Typ, Max)	0.1, 0.5	0.35, 1

TI TechNotes *Offset Correction Methods: Laser Trim, e-Trim ™, and Chopper* **Lit #: SBOT037**

OPAx39x: TI 低压 e-trim™ 运放的家族

产品特点

- **真正的的轨到轨(True-RRIO)输入输出,** 动态电压的摆幅
- **最低失调电压值:** 失调电压最大值为10μV (OPAx392)
- **低偏置电流:** 具有低噪, 高阻抗输入, 良好的传感器对接性能
- **e-Trim™** - 排除封装内应力所导致的参数变化
- **业界同类产品中**具有最高的功耗/带宽的比值

封装选项

Packages: (Released / Sampling / Preview) :

OPA391 (SC-70-5, SOT553-5, VSSOP-8, WCSP) | OPA2391 (RUG, VSSOP-8, WCSP)

Packages: (Released / Sampling / Preview) :

OPA392 (SOT23-5, SC70, WCSP) | OPA2392 (SOIC-8, VSSOP-8, QFN, WCSP) | OPA4392 (TSSOP-14, QFN)

TI TechNotes *Offset Correction Methods: Laser Trim, e-Trim ™, and Chopper*
Lit #: SBOT037

Specifications	OPA391	OPA396	OPA392	OPA397
Vos (max)	45 μV	100 μV	10 μV	60 μV
Vos Drift (typ)	0.1 μV/°C	0.1 μV/°C	0.1 μV/°C	0.1 μV/°C
Ibias (max)	0.8 pA	10 pA	0.8 pA	0.8 pA
Voltage noise	50 nV/√Hz	50 nV/√Hz	6 nV/√Hz	6 nV/√Hz
1/f Noise	4.3 μVp-p	4.3 μVp-p	1.7 μVp-p	1.7 μVp-p
GBW (G=1)	1 MHz	1 MHz	13 MHz	13 MHz
I_Q (max)	21 μA	22 μA	1.22 mA	1.22 mA
Price (1K) (Single)	$0.73	< $0.60 **(低成本)**	$0.83	< $0.60 **(低成本)**

OPA391/6 Applications

- 工业程序自动化设备
- 工业程序控制器
- 医疗设备和仪器
- 电池/电源仪表
- 电源监控器

OPA392/7 Applications

- 光学模块组
- 脉搏血氧仪
- 医疗设备和仪器
- 血糖仪
- 低功耗设备和仪器

OPAx19x: TI's e-trim™ & MUX-Friendly的运放家族

产品特点

- **True-RRIO 36-V CMOS 真正的输入输出电压**
  - 增加输入输出动态电压的摆幅
- **e-trim™**
  - 无封装内应力导致的参数变动
  - 失调电压的选项: **25µV & 100µV (max)**
  - 温漂性能的选项: **0.1, 0.8 & 0.5µV/°C (typ)**
- **MUX-friendly** 的运放能快速, 稳定, 采集DAQ信息的特点. 以防输入信号失真的装况.
- **真正的高阻抗差分输入**
  - 最大差分摆幅高达36 V
  - 最佳用于快速信号输入, 如多路数据采集系统
- **功耗预算选择性：200µA (静态电流)**
- **宽带选项范围：up to 10MHz**
- **低噪音选项范围: 低至5.5nV√Hz**

	Offset 25µV		Offset 100µV	
Specifications	**OPA192**	**OPA191**	**OPA197**	**OPA196**
Supply Voltage	4.5 to 36V	4.5 to 36V	4.5 to 36V	4.5 to 36V
Vos (max)	25µV	25µV	100µV	100µV
Vos Drift (typ)	0.1µV/°C	0.8µV/°C	0.5µV/°C	0.5µV/°C
Ibias (max)	20 pA	20pA	20 pA	20 pA
Noise (@ 1kHz)	5.5nV/√Hz	15nV/√Hz	5.5nV/√Hz	15nV/√Hz
GBW (G=1)	10MHz	2.5MHz	10MHz	2.5MHz
Slew Rate	20V/µs	7.5V/µs	20V/µs	7.5V/µs
I_Q (max)	1.2mA	200µA	1.3mA	200µA
Cap Load	1nF	1nF	1nF	1nF
Price (1ku) (Single)	$1.01	$0.99	$0.53	$0.48

Applications

- 支持多路复合器 DAQs输入
- ADC驱动器
- SAR ADC参考缓冲器
- 电流感测仪

p2p 芯片封装系列的选项:
单通: SOIC-8, VSSOP-8, SOT-23-5
双通: SOIC-8, VSSOP-8
四通: SOIC-14, TSSOP-14, RUM-16

Mux-Friendly, Precision Operational Amplifiers **Lit #: SBOT040B**

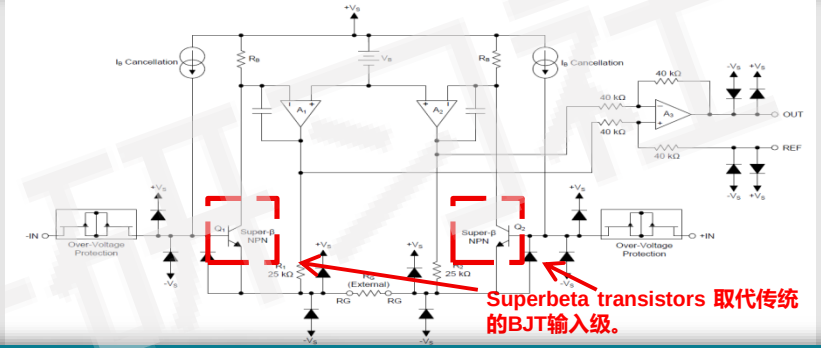
Super–β BJT 双极型输入运放的技术亮点

INA821 | INA818 | INA819 | INA849 | INA848 | OPA2210 | OPA2202/5/6/7 | THP210

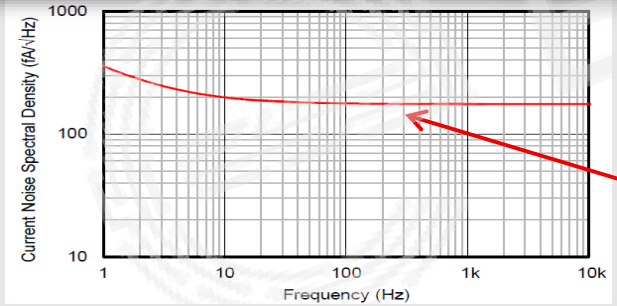
技术概要

- 传统的双极性输入级往往会受到偏置电流的影响，尤其是在与高阻抗源(如电极传感器)对接时。
- 具有Super-β 输入晶体管的双极放大器受益于较低的输入偏置电流和电流噪声，以及更好的输入失调电压和温度漂移。

Superbeta Transistor电路实践

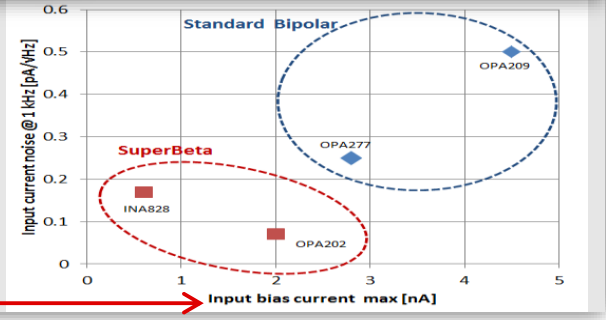


Super –β Transistor 突破哪些技术限制？



使偏置电流在双极型输入放大器中达到Picoamp-level。

低电流噪声使其非常适合与高源阻抗对接。



Application Brief *Super-beta Input Amplifiers: Features and Benefits* Lit #: SBOA305

Super−β 36V输入特性的运放和INA仪表运放的产品

NEW!

Specifications	OPAx202	OPA2205	OPA2206	OPAx210
Vos (μV) (max)	200	25	25	35
Vos Drift (μV/ºC) (typ)	0.5	0.1	0.1	0.1
Ibias (nA) (max)	2	0.75	0.75	2
Input Current Noise (fA/√Hz) (typ)	76	200	200	400
Voltage Noise (nV/√Hz) (typ)	9	7.2	8	2.2
1/f Noise (μV_{pp}) (typ)	0.2	0.15	0.15	0.09
Overvoltage Protection	No	No	± 40V	No

NEW!!

Specifications	INA818/ INA819	INA821	INA828
Vos (μV) (max)	35	35	50
Vos Drift (μV/ºC) (max)	0.4	0.4	0.5
Ibias (nA) (max)	0.5	0.5	0.6
Input Current Noise (fA/√Hz) (typ)	130	130	170
Voltage Noise (nV/√Hz)	8	7	7
GBW (MHz) (typ)	2	4.7	2
Iq (mA) (typ)	0.35	0.6	0.6
Overvoltage Protection	± 60V	± 40V	± 40V

运放应用的领域

- 半导体测试设备
- 数据采集设备 (DAQ)
- 高端医疗仪器
- 超声波设备
- 模拟输入模块

INAs 仪表运放应用的领域

- 生物电极测量仪
- 桥接式传感器测量
- 电流泄漏仪
- 室内外变送器
- 电池测试仪

INA819 and INA821
QFN offerings !!

WSON (8Pin) Package

3 mm x 3 mm

OPAx205 - 36V e-Trim™, Super–β的运放 (250 μA/ch)

BJT双极技术，超高β值, 高精度，低功耗，低噪声，低输入偏置电流

产品特点

• 偏移电压(V_{os}):	25 μV (max)
• 温漂:	0.3 μV/°C (max)
• 输入偏置电流:	0.75 nA (max)
• 电流噪声:	200 fA/√Hz
• 电压噪声:	7.2 nV/√Hz at 1kHz
• 输出短路电流:	25 mA
• 带宽:	3.6 MHz
• 压摆率:	4 V/μs
• 静态电流:	250 μA/ch (max)
• 输入工作电压范围：	4.5V to 36V

Released / Sampling / Preview)

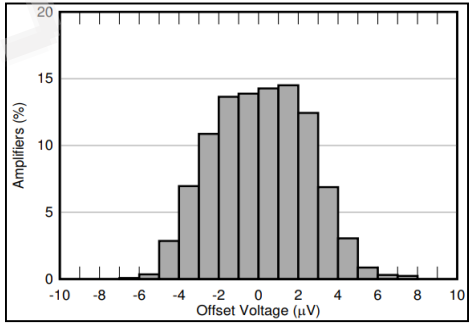
OPA205 (SOIC, MSOP, SOT-23) | OPA2205 (SOIC, MSOP, QFN) |

应用的领域

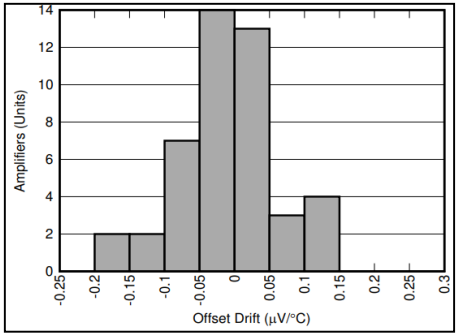
- 工业自动化控制
- 测试与测量
- 传感器与控制器
- 多通道数据采集系统
- 流量仪表
- 模拟输入模块

技术优势

- **e-Trim™ technology** 排除封装内应力所导致的参数变化
- **业界领先的高精度运放**, 偏移电压(25 μV max)，温漂(0.3μV/°C max), 减少了对外围电路校准的需求
- **Super–β运放:** 随环境温差的变化, 有助于降低输入设备的偏置电流和温漂特性
- **低系统噪声和低功耗:** 适用于误差预测低的携带式仪器的设计



低偏移电压(V_{os})



低温漂

OPAx206 – 36V e-Trim™, Super–β的输入运放 (250 μA/ch)

BJT双极技术，超高β值, 高精度，低功耗，低噪声，低输入偏置电流

产品特点

- 偏移电压(V_{os}): **25 μV** (max)
- 温漂: **0.3 μV/°C** (max)
- 输入偏置电流: **0.75 nA** (max)
- 电流噪声: **110 fA/√Hz**
- 电压噪声: **8 nV/√Hz** at 1kHz
- 输出电流: **25 mA** (Short Circuit)
- 带宽: **3.6 MHz**
- 压摆率: **4 V/μs**
- 静态电流: **240 μA/ch** (max)
- 宽工作电压范围: **4.5V to 36V**

Released / Sampling / Preview)

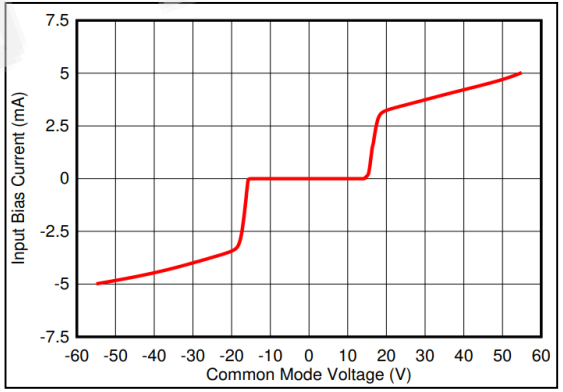
OPA206 (SOIC, MSOP, SOT-23) | OPA2206 (SOIC, MSOP, QFN) |

应用的领域

- 工业自动化控制
- 测试与测量
- 传感器与控制器
- 多通道数据采集系统
- 流量仪表设备
- 模拟输入模块

技术优势

- **e-Trim™ technology** 排除封装内应力所导致的参数变化
- **业界领先的高精度运放**, 偏移电压(25 μV max) , 温漂(0.3μV/°C max), 减少了对外围电路校准的需求
- **Super–β 运放**: 随环境温差的变化, 有助于降低输入设备的偏置电流和温漂的特性
- **低系统噪声和低功耗**, 适用于误差预测低的携带式仪器设计
- **融有过压输入(OVP)的保护系统**, 增强了设备的可靠性



Integrated input overvoltage protection (OVP) protects the system from fault conditions, even when unpowered

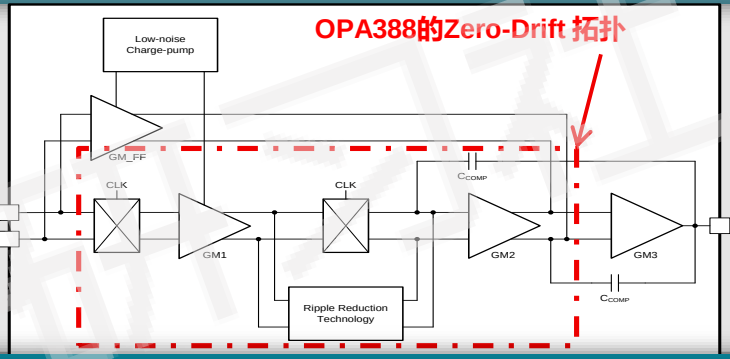
Zero-Drift 零温漂技术亮点

OPA388 | OPA2387 | OPA333/0 | OPA2187 | OPA2182 | OPA2189

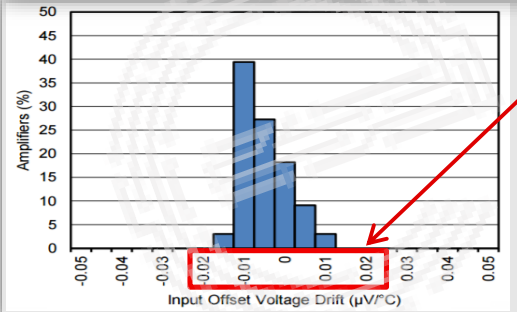
技术概要

- Zero-Drift (分为 Chopper, 斩波运放和 Auto-Zero 两种架构) 运算放大器可连续校正误差， 不断优化运放的失调电压和温漂的影响，并最大限度地降低低频噪声。
- 该电路还可确保绝佳的DC规格（AOL、CMRR和PSRR），从而在恶劣环境中实现更好的性能。

Zero-Drift 电路实践

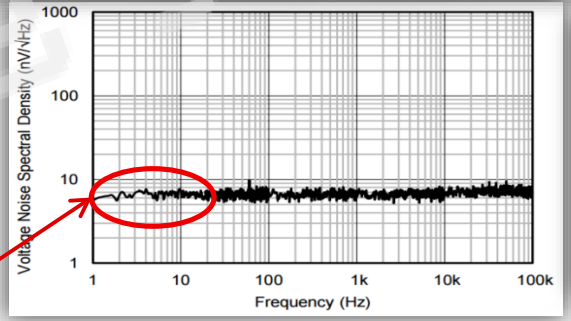


Zero-Drift 突破哪些技术限制？



超低温度漂移
(-40°C to 125°C)

大幅度降低
低频噪音



Specifications	Zero-Drift OPA388	Non-Zero-Drift Amp
V_{os} (µV) (Typ, Max)	0.25, 5	200, 1000
V_{os} drift (µV/°C) (Typ, Max)	0.005, 0.05	0.3, 1.5
0.1Hz - 10Hz voltage noise ($µV_{pp}$)	0.14	2.5

TI TechNotes *Zero-Drift Amplifiers: Features and Benefits"* LIT #: sboa182

TI's Low Voltage Zero-drift Op Amps Family
TI 低压，零温漂运放家族的产品

产品特点

- **OPA388:** 首款并唯一，**零漂移**和**零交叉**轨至轨架构的运算放大器，已通过**AEC-Q100**的签定!
- 超低失调和漂移
  - 无需校准， 增强了直流精度

- **宽带运方：高达10 MHz**
  - 可启用高增益设置
  - 可支持精密电子秤重，心律监测仪等设备

- **低功耗等特点，携带式设计的应用**
  - LPV821 (**650nA**)
  - TLVx333 (**17µA**)

- **p2p 芯片封装家族系列的选项 ***
  - **单通**: SOIC-8, VSSOP-8, SOT-23-5, SC70-5
  - **双通**: SOIC-8, VSSOP-8, SON-8, WSON-8
  - **四通**: SOIC-14, TSSOP-14, RUM-16, VQFN-14

Device	Supply Voltage (V)	Bandwidth (MHz)	Vos (µV) (max)	Vdrift (µV/°C) (typ)	Iq (mA) (typ)	Ibias (pA) (max)
OPA2387 NEW!!	1.7-5.5	5.7	2	0.003	0.57	135
OPAx388	2.5-5.5	10	5	0.005	1.7	350
OPAx333	1.8-5.5	0.35	10	0.02	0.017	200
OPAx330	1.8-5.5	0.35	50	0.02	0.021	500
LPV821	1.7-3.6	0.008	10	0.02	0.00065	--
OPAx335	2.7-5.5	2	5	0.02	0.285	200
LMP2021	2.2-5.5	5	5	0.004	0.95	100
OPA2333P	1.8-5.5	0.35	10	0.02	0.017	200

应用的领域

- 红外传感仪
- 医疗设备和仪器
- 温度测试仪
- 携带式精密传感器
- 电池检测仪
- 电流感测器

*Not all devices listed have all of the package options, refer to the device ds for specific package types

TI's High Voltage Zero-drift Op Amps Family
TI 高压, 零温漂运放家族的产品

Features

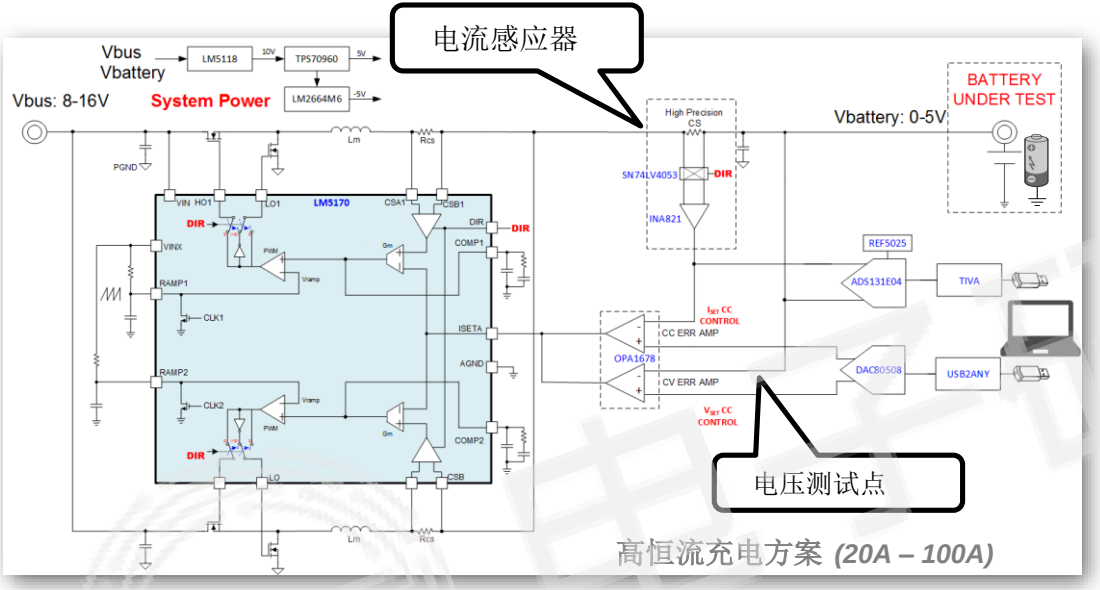
- **业界最低温漂运放的型号 (NEW!)**
  - **OPAx182:** 温漂性能比竞争对手低于**45%**
- **24V 轨到轨输入输出的(RRIO)零漂运放 (NEW!)**
  - **TLVx186**: 此系列唯一一款轨到转输入输出运放
- **高增益带宽的选项 : 从** 0.55 MHz – **14MHz**
  - 可启用高增益设置
  - 多通道数据输入采样系统, 并具有带宽高, 稳定快速输入, 提升吞吐量的运放模拟前端设计
- **降低功耗性能, 不影响其它性能的运放产品:**
  - TLVx186 (90µA) & OPAx187 (100µA)
- **p2p 芯片封装系列的选项:**
  - 单通: SOIC-8, VSSOP-8, SOT-23-5
  - 双通: SOIC-8, VSSOP-8
  - 四通: SOIC-14, TSSOP-14, WQFN-16
- **多通道, 易设制, 高频率输入信号的运放产品**
  - OPAx189, OPAx182, TLV2186

Device	Supply Voltage (V)	Bandwidth (MHz)	Vos (µV)(max)	Vdrift (µV/°C) (max)	Iq (mA) (typ)
OPAx189	4.5-36	14	3	0.050	1.3
OPAx182 NEW!	4.0-36	5	4	0.012	0.85
OPAx188	4.0-36	2	25	0.085	0.385
OPAx180	4.0-36	2	75	0.350	0.45
TLVx186 NEW!!	4.5-24	0.75	250	0.100	0.09
OPAx187	4.5-36	0.55	10	0.015	0.10

高压, 零温漂运放的应用领域

- 秤重测试设备
- 测验设备
- 医疗设备和仪器
- 高精度多通道输入输出系统
- 现场变送器
- 传感器接口与转换器 (如红外，热电偶, 电桥, 热电堆等传感器)

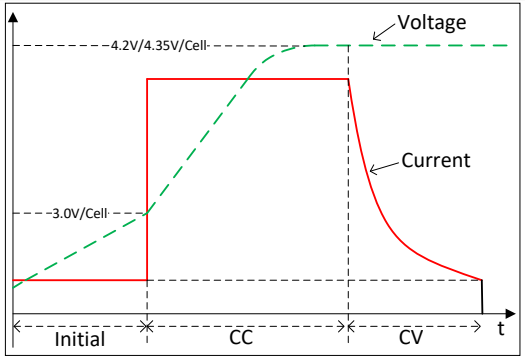
INA821仪表放大器是如何地应用于锂电池测试仪中?



高恒流充电方案 *(20A – 100A)*

INA821如何提升测试仪的系统性能

- ❑ 失调电压 **< 35 μV,** 温漂 **< 0.4 μV/°C,** 增益误差 **< 0.025%**，低电压操声 **7 nV/√Hz**，及对电流测试具用微乎极微的影响:
- ❑ **输入过压保护**: 在Vbus电压浪涌的装况下，INA821具体很可靠的信号输入端的过压保护，高至±40V，大于运放的供应电源.
- ❑ **CMRR >110dB**: 包括所有的运放增益，电流测量系统为独立的，其精度不取决于电池的电压.



典型锂电池充电过程中的程序

功能: 双向电流感测，INA仪表运放可用于电池充电和放电的周期中.两种充电模式:
CC = 恒流充电，CV = 恒压充电

电流感测的要求 :

- 高输入阻抗
- 低温漂 → see analysis next slide!
- 宽共模输入电压 (Vcm)范围

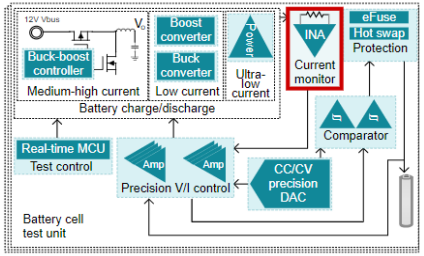
明星产品: INA188, INA821, INA818/9

TI TechNotes

"Comprehensive Error Calculation for Instrumentation Amplifier"
ti.com/lit/sboa341

锂电池电流感应测试 – 仪表放大器IC的选项

功能



功能 – 通过分流电阻器测量电池的充电/放电特性

- 典型的分流器阻值约< 0.5Ω，小的阻值需要更高的增益，可充分利用运放的动态的电压摆幅
- 精确的电流测量至关重要 – 可用于估算电池容量，输出阻抗，甚至可对剩余的电池寿命进行预测等指标.

通常使用仪表运放来设计 – 与带有集成分流器运放的电流感应芯片相比，其优势包括：

- 高输入阻抗
- 低噪音特性
- 可调增益的优化性
- 超高共模输入抑制比 (CMRR)

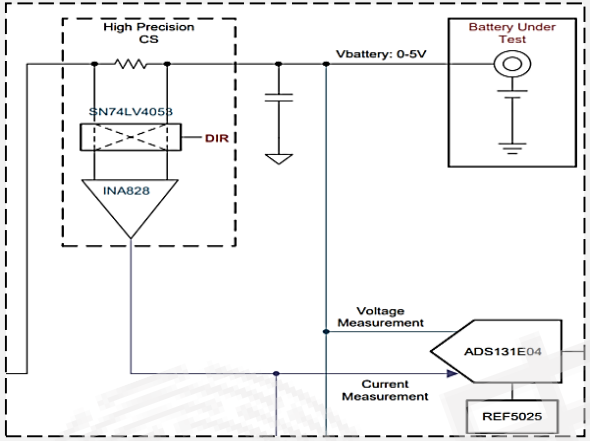
推荐的芯片

	Highest BW Low Noise	Mid BW Low Noise	Mid BW Lower Power	Lowest Drift
Specifications	**INA821**	**INA828**	**INA819**	**INA188**
Vs min (V)	4.5	4.5	4.5	4
Vs max (V)	36	36	36	36
GBW (MHz) (G=1)	4.7	2	2	0.6
Slew Rate (V/µs)	2.1	1.2	0.9	0.9
Vos max (µV)	35	50	35	55
Drift (Max) (µV/C)	0.4	0.5	0.4	0.2
CMRR (Max Gain) (Min) (dB)	140	140	140	118
Iq typ (mA)	0.6	0.6	0.35	1.6
Vn (nV/rtHz)	7	7	8	12.5
Ibias (Max) (nA)	0.5	0.6	0.5	2.5
Gain Error (% Max)	0.15	0.15	0.15	0.5
Gain drift (ppm/°C)	35	50	35	50
Price (web $)	2.21	2.15	2.05	1.85

PRAMPS| EE: 电池测试仪

电流感应测试器

电流感测示意框图



有参考价值的设计和资料

- Product folder – INA821
- SBOA341 – Comprehensive Error Calculation for INAs
- SBOA236 - Simplify V & I measurement in battery test
- TIDA-01040 - Batter tester for high current applications
- [FAQ] INA Stickie: How do INAs fit into my design?

设计的难题和挑战

1. 提高CC/CV控制回路的精度(<0.1%)，如输出阻抗，电池容量值(SOC)和电池健康状况(SOH) 等相关参数.
2. 高带宽 对于数字反馈配置是必需的（模拟配置不需要高带宽）

产品的主要特性和性能的亮点

1. **High Precision**: INA821 Super-beta inputs enable low drift to ensure accuracy over wide temperature ranges (**0.4µV/°C max**), low offset voltage to minimize system error (**35µV max**) and extremely low gain error for accurate reading **0.005%** (G=1).
2. **High Bandwidth:** INA821 Current feedback input stage provides high common-mode rejection and bandwidth for higher gain settings
3. **Low noise:** INA821 offers low 1/f and broadband noise help ensure maximum signal integrity and optimum resolution

Device	Description
INA821	Wide-bandwidth (4.7MHz), high-precision (35µV, 0.4µV/°C), low noise (7nV/√Hz), instrumentation amp with input overvoltage protection
INA818	Low power (350µA), high-precision (35µV, 0.4µV/°C), low noise (8nV/√Hz), instrumentation amp with input overvoltage protection
INA188	Zero-drift (55µV, 0.2µV/°C), low noise (12nV/√Hz), instrumentation amp with RFI filtered inputs and wide-supply (36V)

高精度运放工业领域的现场变送器

Field Transmitter

设计出发点

在苛刻的供应链环境下，工厂设备的管理需要越来越复杂的自动化解决方案。 自动化设备需要对气压，温度感应器和流量传感器等参数必须进行更准确的测量.

Factory Automation & Control	Sub-system 子系统	传感器的技术类型	明星产品
传感器	• 流量传感器	• Electromagnetic • Ultrasonic • Thermal mass • Differential pressure flow	• INA821 • INA819 • INA826 • INA333 • OPA2376 • OPA2191
	• 温度感应器	• Thermocouples • Resistance temperature detectors (RTDs)	
	• 压力感应器	• Resistive bridge • Capacitive bridge • Linear Variable Differential Transformers (LVDTs)	
监控器	• 4-20 mA 变送器	• Loop powered transmitter • 3-wire transmitter	• XTR111 • XTR115 • XTR305 • OPA391 • OPA333

设计的难题和挑战

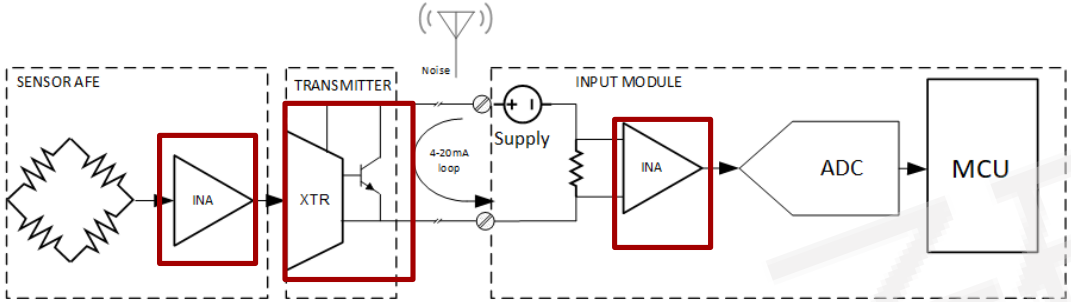
有不同技术含量及多元化的传感器设计 ， 更不用提电路设计的精度和需求。以下为常见的设计要求, 其包括:

低功耗 对于环路供电电源的应用至关重要
高共模抑制比 减小外界信号耦合的敏感性
低温漂 在苛刻的工作环境中提高准确性
低操声 保持信号完整性和高分辨率
微小封装 减少IC占用面积, 增加测量通道, 获得更多测试参数

Field (现场) – 指的是室内外, 工作环境苛刻, 操作环境无法控制的测试和测量或监测等应用场合.

4-20 mA工业领域的现场变送器 – Field Transmitter

简化的变送器和模拟量输入模块图



Instrumentation amplifier to condition transducer signal and current measurement

INA333 – Micro-power (50µA), zero-drift (0.1µV/°C), high precision (25µV)
INA821 – High precision (35µV), wide bandwidth (4.7MHz), low noise (7nV/√Hz) with over-voltage protection
INA818 – Low power (350µA), high precision (35µV), low noise (8nV/√Hz) with over-voltage protection
INA188 – 36V zero-drift (0.2µV/°C), precision (55µV), with RFI filtered inputs

Transmitter converts signal from sensor to 4-20mA:

XTR115 – includes 5V regulator and 2.5 V reference
XTR116 – Includes 5V regulator and 4.096 V reference
XTR117 – Includes 5 V regulator
XTR305 – Industrial analog current to voltage output driver

Discrete implementations of signal conditioning and transmitter functions

OPA391 – Micro-power (24µA), ultra-low bias (10fA), precision (45µV) op amp
OPA2387 - Ultra-high precision (2µV), zero-drift (0.003µV/°C), low 1/f noise (177nVpp) op amp
OPA2187 – High precision (10µV), zero-drift (0.001µV/°C), low power (100µA) op amp
OPA2205(6) – Precision (25µV), low 1/f noise (150nVpp), low power (250µA) bipolar op amps with over-voltage protection

4-20mA 电流回路的应用

- 尽管某些传感器具有I2C数字输出的集成功能，但传感器需要输出差分信的进行调理.
- 调节后的输出信号转换为管控行业的标准4-20mA电流环路，即电压与电流的转换.然后将输出的电流输入摇控端的PID控制器.
- 从电流回路转换为电压，以便对远程距离的遥控设备进行信号处理或PID的管控.

TI现场变送器的资源

- Highly Accurate, Loop-Powered, 4- to 20-mA Field Transmitter With HART Modem Reference Design
- How to Select Amplifiers for Pressure Transmitter Applications
- Digitally Calibrated Bridge Sensor Signal Conditioner with 4mA to 20mA Current Loop Output
- Compact Programmable 4-mA to 20-mA and ±10-V Analog Output Reference Design for AC/Servo Drives
- Single-Supply Analog Input Module Reference Design with 16-Bit, 8-Channel ADC for PLC

如何应用高精度动放配备的– 现场变送器

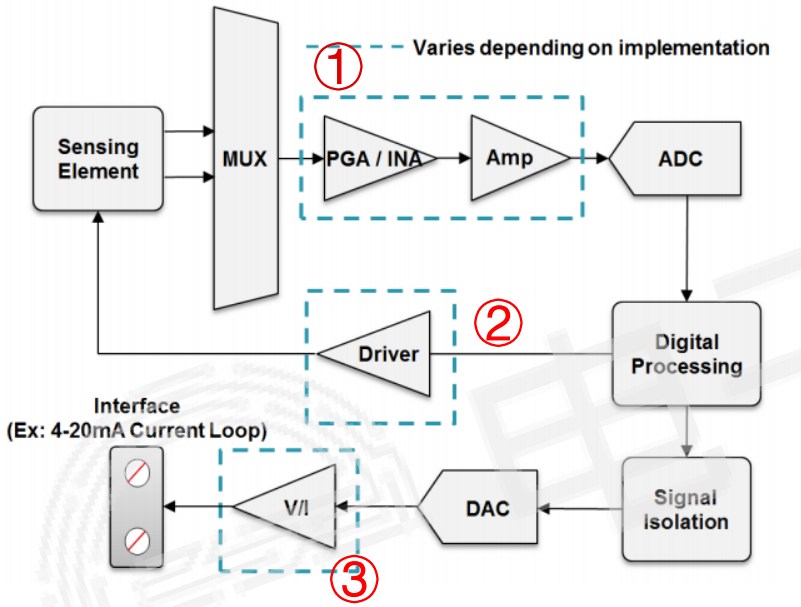


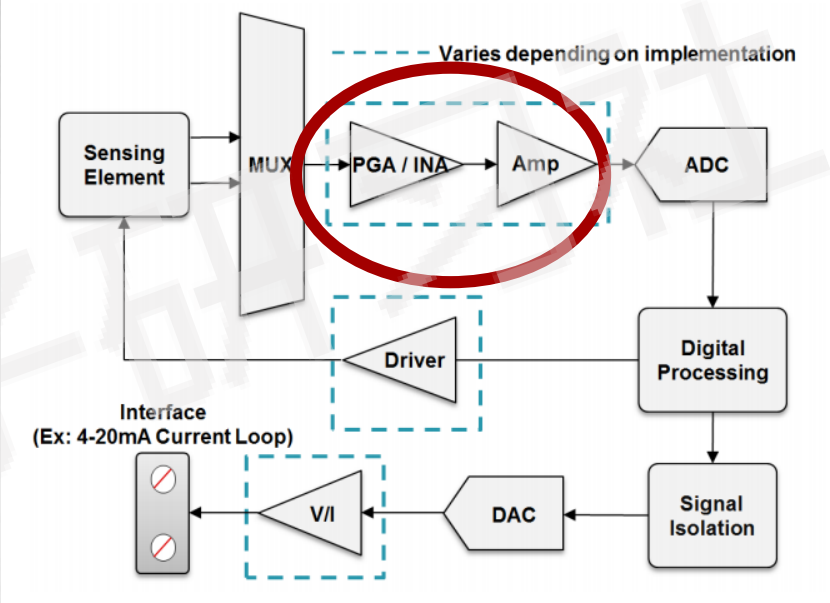
Figure 1. Common Pressure Transmitter Block Diagram

1. **PGA/INA:**当微小的差分信号在苛刻的工作环境下，如变化信号覆盖于较高的共模信号或噪声装况下，PGA仪表运放用于其可挑的高增益特性来放大的这些微小的差分信号，衰减抑制共模噪声所带来的影响，提高的更准确的增益精度。

2. **驱动器:** 当需要使用运放驱动器来控制及提供可靠的激励电压时，如电容式，LVDT和硅基等传感器，来获得对气压，位移等感测信息的变化。

3. **V/I 转换器:** 是非常可靠和普遍使用的电压与电流信号之间的转换器，常用于4-20mA电流环路来PID遥控和操纵工业上的测试器材，是模拟数据传输的标准信号和信息转换的理想选择

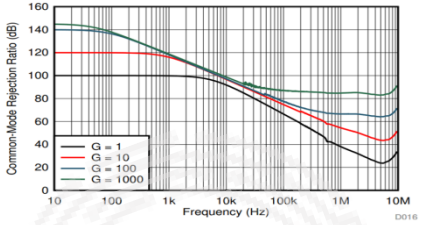
INA 仪表运放的明星产品
对现场变转器的应用



INA 仪表运放在现场变送器领域的应用优势

i. **设计中要考虑的因素 (INA) #1 – 高共模输入抑制比，CMRR=140dB @G=100**
ii. **设计中要考虑的因素 (INA) #2 – 低输入偏置电流(失调电流)**
iii. **设计中要考虑的因素 (INA) #3 – 低噪声**
iv. **设计中要考虑的因素 (INA) #4 – 低功耗→ 回路供电电源, 2-wire 现场变转器的设置**

Sensor imbalances and environmental conditions create significant AC and DC common-mode voltages. High CMR across frequency is required.

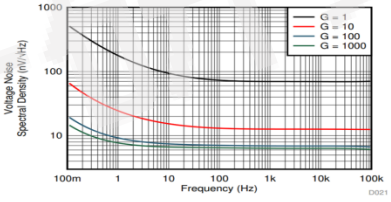


#1

INA821
CMR (G=100) = 140-dB

INA821 offers **unmatched** CMR across frequency at different gain configurations.

Small differential voltage at the sensor output require low noise to maintain the integrity of the signal. This is especially important in high resolution flow meters with µV-level sensitivity.

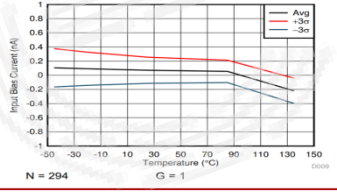


#3

INA821
1/f (G=100) = 0.14 µVpp
En (G=00) = 7 nV/√Hz

INA821 offers **extremely low 1/f corner** and overall excellent noise performance. Up to an **83%** reduction in 1/f noise when compared to its competitors.

Flowmeter sensors can have output impedance up to the GΩ range. It is important to keep bias current low to avoid generating additional input errors. Make sure performance is maintained across temperature (**JFET amps will increase orders of magnitude across temperature**).

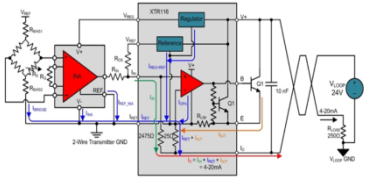


#2

INA821
Iv (@ 25°C) = 0.5 nA

INA821 offers **very low** input bias current and shows excellent performance across a **wide temperature range**.

AFE power consumption dictates the current level at which the XTR functions. For 4mA loops, you want the AFE to consume little power:



#4

INA821
Iq = 0.6-µA

INA821 offers up to a **67%** reduction in quiescent current when compared to its top competitors

INA 仪表运放明星产品在现场变送器领域的应用特性

Specifications	INA821	INA818	INA333	INA188
Supply Voltage (V)	4.5 < Vs < 36	4.5 < Vs <36	1.8 < Vs < 5.5	4 < Vs < 36
CMRR (G=1000) (dB) (Min)	140	140	100	118
Input Offset (µV) (Max)	35	35	25	55
Input Offset Drift (µV/°C) (Max)	0.4	0.4	0.1	0.2
Input Bias Current (nA) (Max)	0.5	0.5	0.2	2.5
Noise @ 1kHz (nV/√Hz) (Typ)	7	8	50	12.5
Quiescent Current (mA) (Typ)	0.6	0.35	**0.05**	1.4
Bandwidth (Min Gain) (MHz)	4.7	2	0.150	0.60
Gain Error % (Max) (G=1)	0.025	0.025	**0.1**	**0.025**
Specified Temperature (°C)	-40 to 125	-40 to 125	-40 to 125	-40 to 125
Package Options	MSOP-8, SO-8, QFN	SO-8	MSOP-8, SO-8, QFN	MSOP-8, SO-8, QFN
Other features	±40V input protection; Super-beta	±60V input protection; Super-beta	Zero-drift Micro-power RFI filtered inputs	Zero-drift RFI filtered inputs

传感器系统应用现场变送器后所获得产品性能的优势/提升

1. 高CMRR：高共模抑制比可减少传感器连续校准的需求
2. **高输入阻抗:** 由于传感器的输出阻抗可能高至GΩ的范围，因此现场变送器必需具有更高的输入阻抗.
3. **高电气过应力(EOS):** 每输入端各设有过压的保护电路，高至 $\pm 40V$，对操作环境所产生的诱发干扰信号具有很好的容错保护作用.
4. 低功耗

Reference:

- TI Precision Labs - Op Amps: Instrumentation Amplifiers
- What is an instrumentation amplifier?
- Comprehensive Error Calculation for Instrumentation Amplifiers
- How to layout a PCB for an instrumentation amplifier

INA849 36V Instrumentation Amplifier (28 MHz)

业界领先，超低噪声，高带宽，高精度的仪表放大器

产品特点

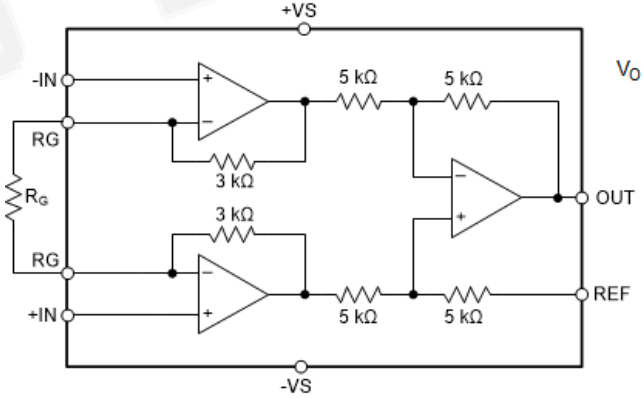
- 电压噪声: **1 nV/√Hz** at 1kHz
- 电流噪声 **1.6 pA/√Hz** at 1kHz
- 带宽: **28 MHz**
- 压摆率: **35 V/μs**
- 偏移电压(V_{os}): **35 μV** (max)
- 失调电压漂移: **0.4 μV/ºC** (max)
- 共模抑制比 CMRR (高增益下): **120 dB** (min)
- 输入偏置电流(I_{bias}): **20 nA** (max)
- 增益误差: **0.05 %** (max)
- 静态电流: **6.6 mA** (max)
- 宽输入工作电压范围: **8V to 36V**

应用的领域

- 光纤网络监控仪
- 超声波扫描仪
- 流量变送器
- 心电图 (EKG) 放大器
- 电池检测仪设备
- 工业流程分析仪
- 医疗仪表设备
- 便携式仪表设备

产品性能优势

- **业界最低噪**, 低失真仪表放大器，可用于超声扫描仪和振动分析仪等高精度数据采集系统, 并提供更高分辨率.
- **领先于业界**的竞争对手, 拥有**最高带宽的仪表放大器**，具备更低的静态电流与带宽的比值
- **低输入失调和低温漂**的特性, 可用于电池测试仪和示波器等的系统设计, 提供极其精确的测试测量.
- 固定增益的运放(G = 2,000)可用型号: **INA848**



$$V_O = G(V_{+IN} - V_{-IN}) + V_{REF}$$

$$G = 1 + \frac{6\ k\Omega}{R_G}$$

现场变送器的选项 – 明星产品
V/I 转换器的运放芯片

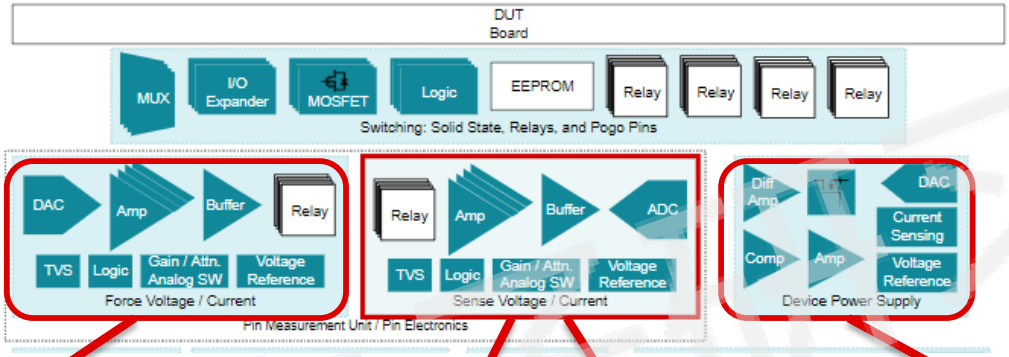
2-Wire		
Specifications	**XTR115/6**	**XTR117**
Description	Current in to Current Out	Current in to Current Out
Supply Min (V) Max (V)	7.5-36	7.5-36
Output Range	0-20mA	0-20mA
Input Range	0-250uA	0-250uA
Sensor Excitation	2.5V/4.096V	-
Quiescent Current(μA)	200	130
Nonlinearity Error(%)	0.003	0.003
Onboard Regulator	5V	5V
Package(s)	SO-8	VSSOP-8,SON-8
Price(Web)	1.25/1.5	0.9

3-Wire		
Specifications	**XTR111**	**XTR300/XTR305**
Description	Precision V-to-I Converter	Industrial Analog Current/Voltage Output Driver
Additional Features	Adjustable Regulator	Digital Mode Control, Error Status Flags, Voltage or current out, Monitor circuitry
Supply Min (V) Max (V)	8-40	10-40
Output Range	0-20mA/4-20mA/5-25mA	±17V ±24mA
Input Range	0-12V	$(V_- + 3V)$ to $(V_+ - 3V)$
Sensor Excitation	-	-
Onboard Regulator	Adjustable 3V - 15V	-
Package(s)	MSOP-10. VSON-10	QFN-10
Price(Web)	0.65	1.00

References:

- Using the XTR115 with the PGA309 to Generate 4mA to 20mA Output (Rev. B)
- Compact Programmable 4-20mA and +/-10V Analog Output Reference Design

高精度运放在测试与测量中的应用
电子设备(EE):半导体业的芯片测试器材



Precision Amplifiers

DUT Excitation

>36V — New
OPA462
180V, 3.4mV, 6.5MHz, 33nV/rtHz
Top Competitors:
- LTC6090, ADHV4702

>36V — Pre-RTM
OPA593
85V, 100uV, Current Limit
Top Competitors:
- LT6015, ADA4700

ADC Buffer

New
OPA2210
36V, 35uV, 18MHz, 2.2nV/rtHz
Top Competitors:
- AD8676, AD8672

ADC Driver

New
THP210
36V, 50uV, 10Mhz, FDA
Top Competitors:
- ADA4945-1

Differential V/I Sensing

INA149
High Vcm , diff amp
Top Competitors:
- AD629

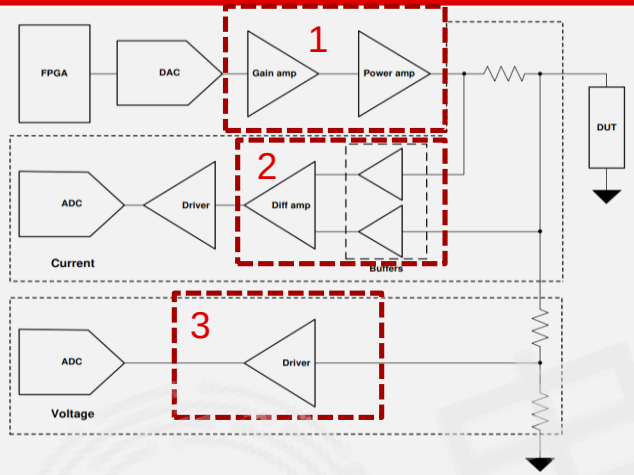
Voltage Sensing

OPA2189
36V, 3uV, 14MHz, 5.2nV/rtHz
Top Competitors:
- ADA4522

以上所有提到的失调电压值均为最大值

PRAMPS| EE:半导体业的芯片测试设备

应用范围：输入缓冲器和故障保护



TI 推荐的芯片

Device	Description
OPA455	Wide-supply (150V), wide bandwidth (6.5MHz) unity gain stable op amp with current limit and status flags
INA149	High common mode (550V) unity gain difference amplifier
OPA2182	Industry's lowest drift (0.12nV/°C), very low offset (4μV), low noise (5.7nV/√Hz)
THP210	Industry's only precision (40μV, 0.35μV/°C), lower power 36V fully-differential ADC driver

设计的难题和挑战

半导体和存储器测试设备需要配置高电源和高电流输出功率的放大器。如今这些操作系统采用了DAC转换器，增益和高功率运放等配置，对被测器材施加电压。 然后监测，以确保被测芯片的正确响应。

特性功能

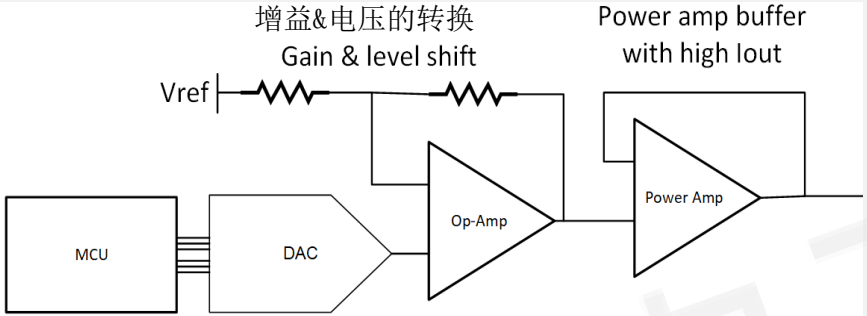
1. DAC provides a voltage from 0-2V and needs to be gained up by an amplifier. This voltage is then driven by a power amplifier with enough current output.
   - Power amp should be chosen based on the current needs of the application and the supply voltages available.
   - Depending on the gain required, a separate gain amplifier is needed to preserve power amplifier bandwidth
2. Precision current sense is needed to monitor overcurrent conditions and ensure proper test conditions.
3. Voltage must be monitored to ensure that the proper test conditions are being evaluated. This can be done using a simple resistor divider and driving the ADC.

PRAMPS| EE:半导体业的芯片测试设备

1: 使用高功率运放对被测设备(DUT) 提供电源的需求

应用范围：输入缓冲器和故障保护

高功率高输出电流的运放缓冲器



设计的难题和挑战

半导体测试仪的输出端需要高带宽和电源范围宽的运放，以获得DAC增益电压的输出值高至35倍之多。 操作的运放还必须具有高输出电流的功能（高至200 mA），以获取多用户产品测试的需求和兼容性。

产品的主要特性和性能的亮点

德州仪器的产品组合中提供高输出电流，宽电源，高带宽，高功率的运放芯片，视如下。

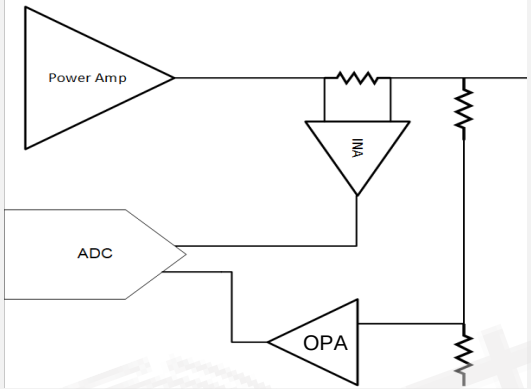
Specifications	OPA462	OPA455	OPA454
Supply Voltage (V)	12 to 180	12 to 150	10 to 100
GBW (MHz)	6.5	6.5	2.5
Slew Rate (V/µs)	32	32	13
Output Current (mA)	45	45	120
Vos max (mV)	3.4	3.4	4
Drift typ (uV/C)	4	4	1.6
Features	Current limit	Current limit	Current limit

有参考价值的设计和资料

- How to Select Precision Amplifiers for Semiconductor Testers

2. 电流和电压感应测试

应用范围：输入缓冲器和故障保护



TI 推荐的芯片

Device	Description
INA821	Wide-bandwidth (4.7MHz), high-precision (35µV, 0.4µV/°C), low noise (7nV/√Hz), instrumentation amp with input overvoltage protection
INA149	High common mode (550V) unity gain difference amplifier
INA188	Zero-drift (55µV, 0.2µV/°C), low noise (12nV/√Hz), instrumentation amp with RFI filtered inputs and wide-supply (36V)
OPAx182	Industry's lowest drift (0.12nV/°C), very low offset (4µV), low noise (5.7nV/√Hz

设计的难题和挑战

电流和电压监控系统为确保芯片的正常操作性能和要求起到关键作用，并对被测芯片在检测过程中可能发生的超载电流装况等参数进行探测.

产品的主要特性和性能的亮点

电流检测功能可以使用高压仪表运放来完成。 如有特高共模电压输入的检测装况下，可以使用INA149差分运放。

电流感应测试的关键需求：

1) 高共模抑制比
2) 低偏移电流和漂移
3) 低噪声

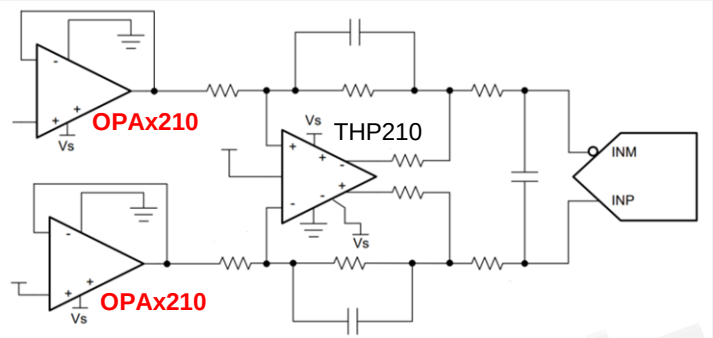
电压感应测试的关键需求：

1) 低偏移电压和漂移
2) 低噪声

PRAMPS| EE:半导体业的芯片测试设备

3:高精度，低噪声，ADC缓冲器和驱动器的运放

应用范围 ：ADC缓冲器



有参考价值的设计和资料

- Why precision matters with fully differential amplifiers
- How to Select Precision Amplifiers for Semiconductor Testers
- SLYY137 – Analog Engineer's Circuit Cookbook: Amplifiers
- SLYT701 - The Signal E-Book

设计的难题和挑战

达到符合低失真和低噪声实现数据采集。 信号链输入口的前端需要配置一款宽输入电源, 高精度， 低噪声的运放。

产品的主要特性和性能的亮点

ADC 驱动器和缓冲器的要求：

低噪声：

- Low noise and low distortion allow for high resolution data acquisition.

高精度：

- Low Offset Voltage, and Low Offset Voltage Drift

高带宽和高速 ：

- Bandwidth: 18 MHz (Typ) | Slew Rate: 6.4 V/µs (Typ)

TI 推荐的芯片

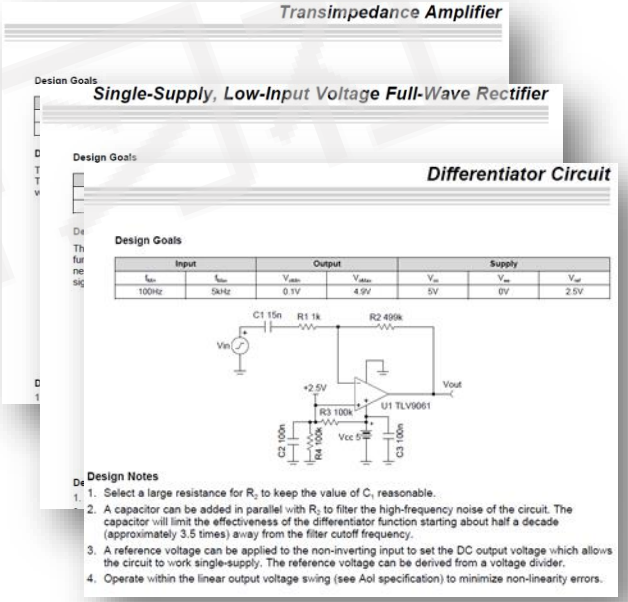
Device	Description
THP210	36V, low power (950µA), low noise (3.7nV/√Hz), high precision (40µV, 0.35µV/°C) fully-differential ADC driver
OPAx210	Ultra-low noise (2.2nV/√Hz), wide bandwidth (18MHz), precision (35µV), Super-beta op amp
OPAx206	High precision (35µV, 0.3µV/°C), low noise (7.2nV/√Hz), Super-beta, e-Trim op amp with OVP

Analog Engineer’s Op-Amp Cookbook
运算放大器电路设计指导手册

Analog Engineer’s Op-Amp Cookbook:

- 包括常见运算放大器拓扑的示例
- 详细电路设计解说。
- 提供独特的放大器电路，包括SPICE模型，可应用在任何终端产品。
- 包括 >25个常见运算放大器电路，从反相放大器到PWM生成等。
- **在ti.com网站上可免费下载。**

立即在 TI.com上下载！



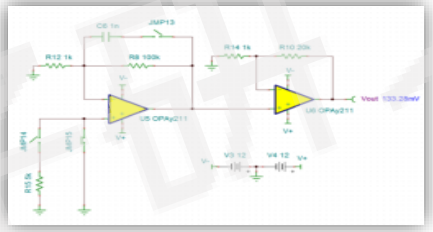
中文版： http://www.ti.com.cn/zh-cn/analog-circuit/circuit-cookbook.html
英文版： *www.ti.com/CircuitCookbooks*

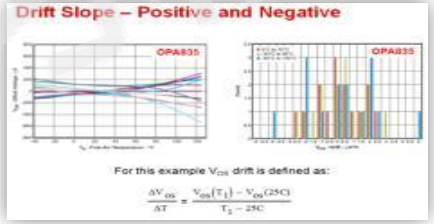
TI Precision Labs – TI 高精度实验室在线模拟课堂

www.ti.com/precisionlabs

中文版： https://www.ti.com.cn/ww/seminars/PLAB/index.html

- 每个视频 <15 分钟
- 附上测验及模拟教学的专业讲座
- 不同经验级别的人都能从视频中受益





Op Amps

Input Offset Voltage (V_{OS}) & Input Bias Current (I_B)
TIPL 1100
TI Precision Labs – Op Amps
Presented by Ian Williams
Prepared by Art Kay and Ian Williams

Comparators

Comparator Applications 3
TIPL 2103
TI Precision Labs – Op Amps
Presented by Ian Williams
Prepared by Thomas Kuehl and Ian Williams

MUXes

Basics of Analog Multiplexers 2
TIPL 2602
TI Precision Labs – Op Amps
Created by Abhijeet Godbole, Art Kay
Presented by Peggy Liska

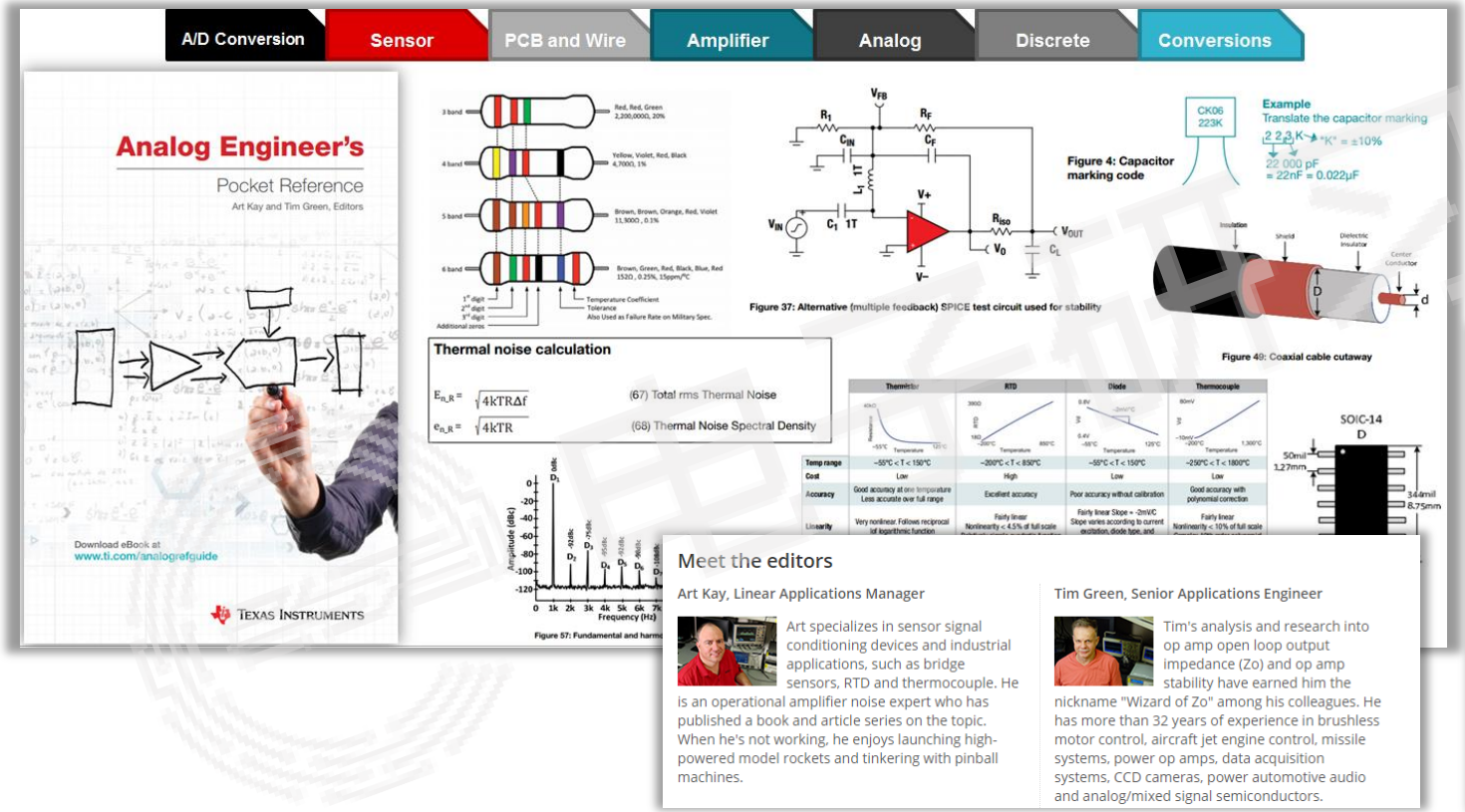
ADCs

DC Specifications:
input capacitance, leakage current, input impedance, reference voltage range, INL, and DNL
TIPL 4001
TI Precision Labs – ADCs
Created by Art Kay
Presented by Peggy Liska

超过70个视频 !!!

TI's Analog Pocket Reference Guide
模拟工程师口袋参考书

下载： https://www.ti.com/seclit/ml/slyw038c/slyw038c.pdf



App for your mobile

TI Amplifier Macromodel

运算放大器的最佳建模

准确性

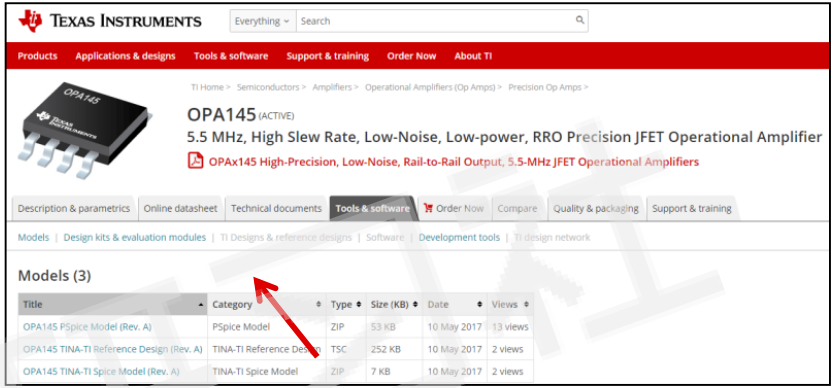
- 所有运放的主要参数均可根据其产品的数据规格性能表进行精确建模
- 正在添加更多参数以进一步提高未来准确性

速度

- 系统优化造就更快的仿真时间
- 快速拓展電路数据库已提升用户体验

兼容性

- 兼容所有基于PSpice的仿真软件
- 提供业内最佳的质量控制

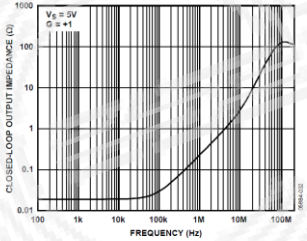


在TI.com产品页面的“Tools & Software”栏位可找到相关模型

输出阻抗仿真

对手准确度

Datasheet



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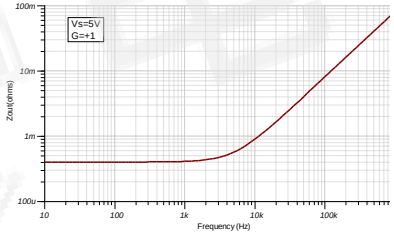
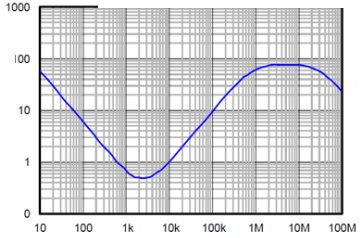


- 输出阻抗的不准确实现
- 对于小信号稳定性分析或驱动动态负载的仿真不准确

TI 准确度

Datasheet



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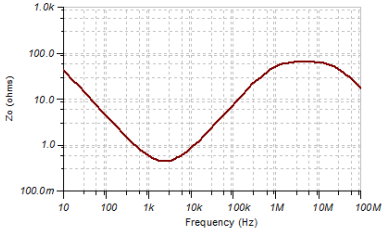


- 详细且准确地实现输出阻抗
- 使设计人员对小信号仿真行为有更高的信心

TI Precision Labs (TIPL)

高精度实验室–运放在线的学习视频

TI Precision Labs – Chinese Websites

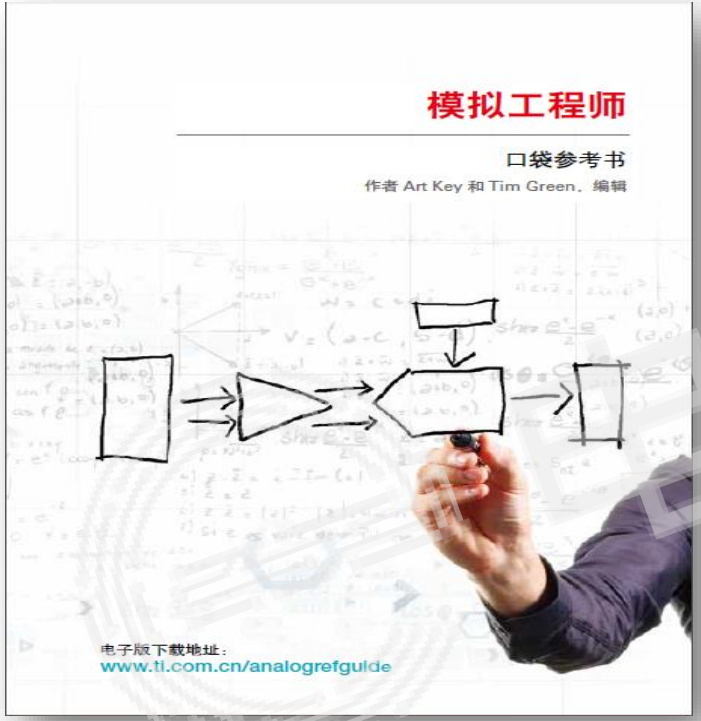
TI 高精度模拟实验室视频 –中文版本网站地址

德州仪器官网 TI.com.cn

德州仪器官方小程序

德州仪器
小程序

模拟工程师的随身参考：可随时查阅板级和系统级公式



- 涵盖广泛、备受欢迎的高精度信号链课题：
  - ✓ 运算放大器的带宽和稳定性
  - ✓ 模拟/数字（A/D）和数字/模拟（D/A）转换
  - ✓ 更多精彩，敬请下载随身参考……
- 由TI运算放大器专家Art Kay和Tim Green编辑
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