电压基准源的产品及选择

July 2019

AHEAD OF WHAT'S POSSIBLE™

讲座议程

- 电压基准源的基本概念
  - 分类
  - 主要参数
- 如何选择电压基准源
- 几款电压基准源产品推荐

什么是电压基准源（Voltage Reference）？

- 电压基准源是一个可产生稳定、精确直流电压的器件，一般用于ADC、DAC和其他模拟电路精确的参考电压设定。

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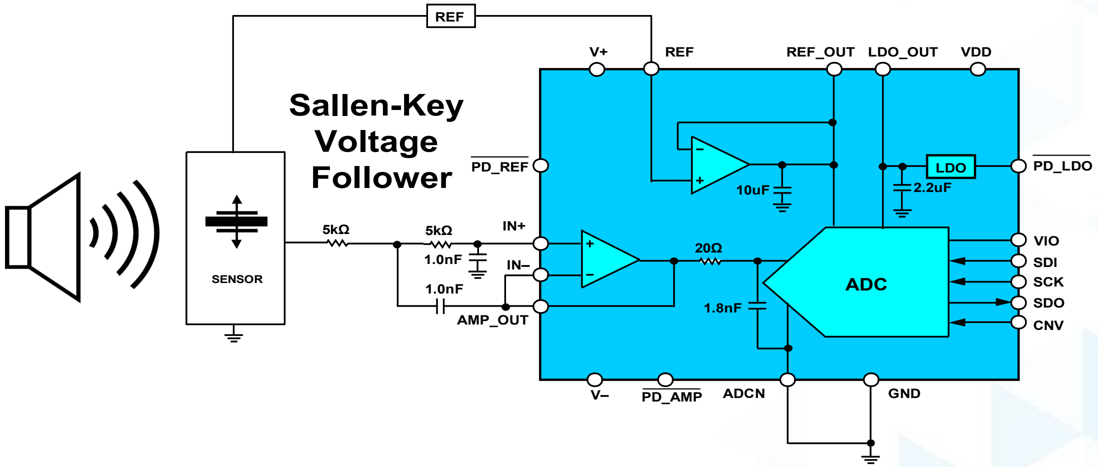
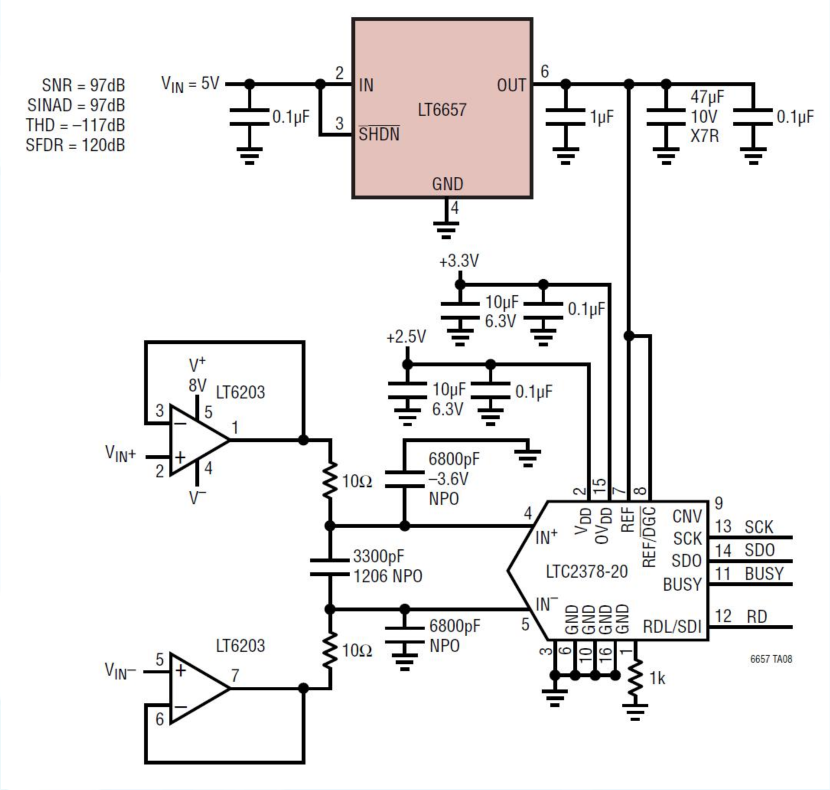
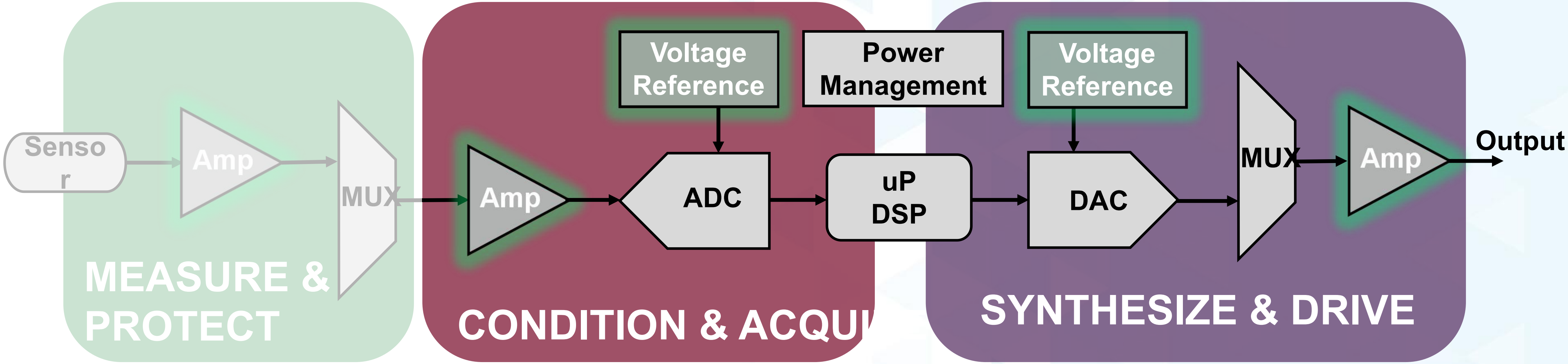
- 电压基准源的一般用途
  - ADC/DAC参考源
  - 传感器的偏置
  - 元器件/系统供电或驱动
  - 虚拟地设置

ADXL1002 **ADAQ7980**



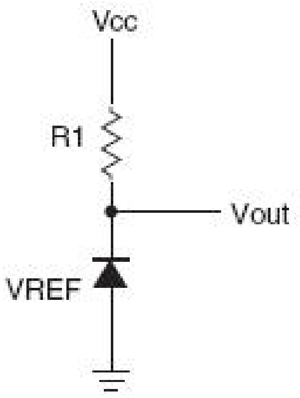


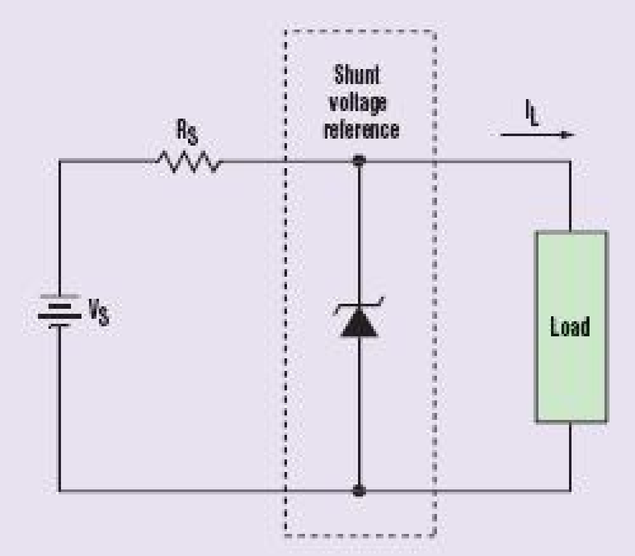
电压基准源的作用：将数据采集与真实世界进行关联



电压基准源的分类（按应用拓扑）

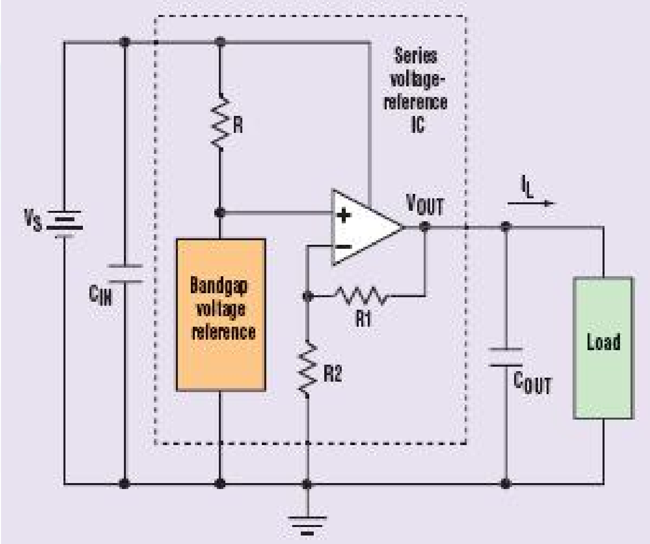
Shunt Reference
并联型电压基准源

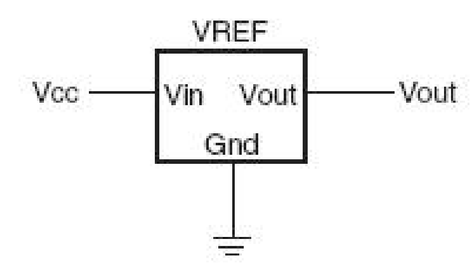




- A two-terminal Device
- Need for an extra resistance
- Need more board space
- Usually smaller packages
- Tends to be cheaper
- （Lower Precision）

Series Reference
串联型电压基准源





- A three-terminal device
- No need for an extra resistance
- Typically lower Vin range
- Might be in a larger package
- More accuracy

电压基准源的基本特性：精度和稳定性

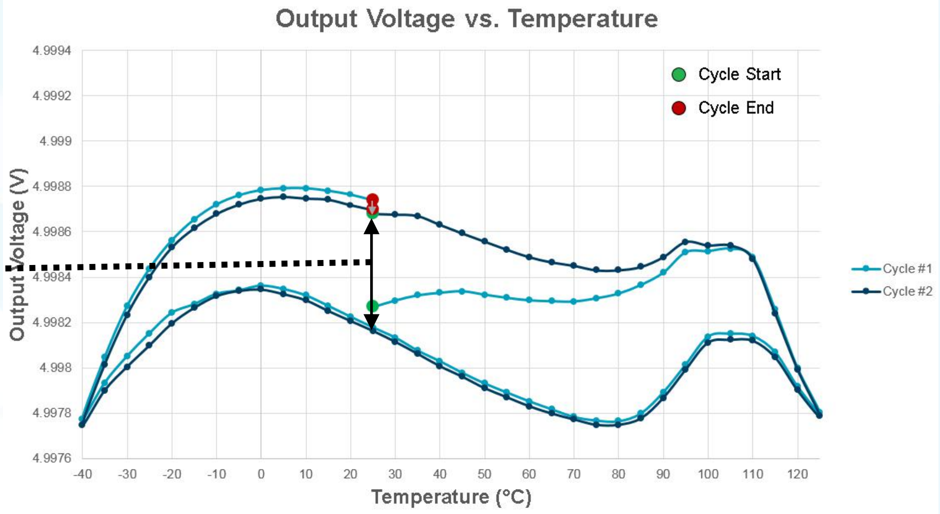
- 电压基准源的基本性能要求
  - 高精度
  - 低噪声
- 电压基准源必须在下列情况下保持稳定
  - 温度变化 => 温度系数
  - 温度循环 => 热迟滞
  - 环境压力变化 => 无规定
  - 湿度变化 => 没有对应的性能参数规定
  - 时间的变化 => 长期稳定性

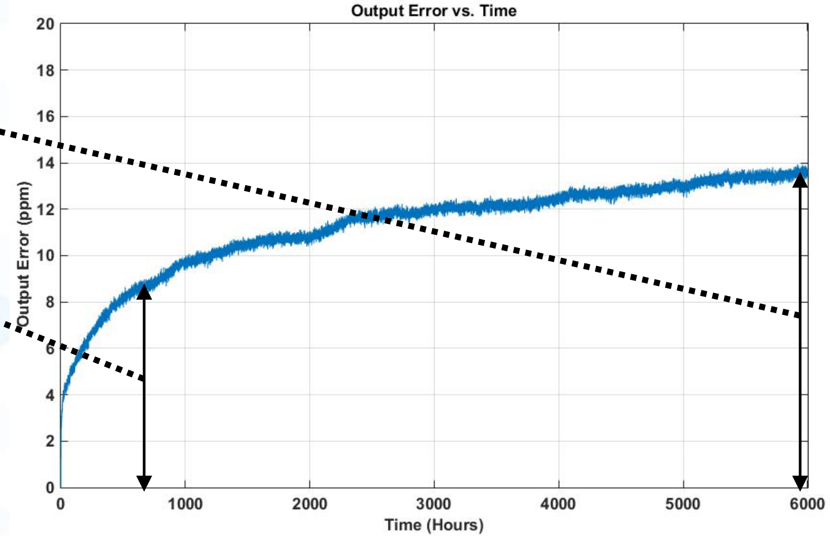
Common VREF Applications

- Converter reference
- Sensor bias
- Component or system power
- Virtual ground

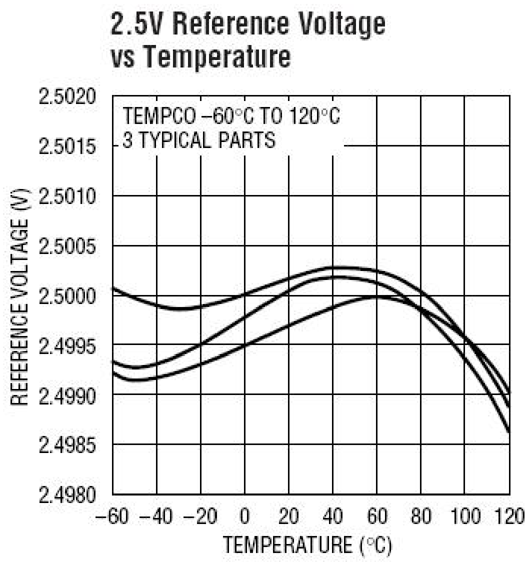
电压基准源几个关键性能指标

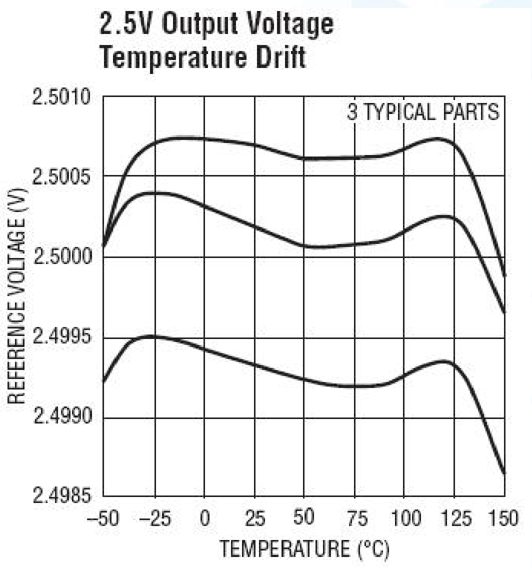
- 初始精度 (Initial Accuracy) 或初始误差（Initial Error）
- 温度漂移（Temperature Drift）或温度系数（Temperature Coefficient）
- 噪声Noise
  - 1/f 噪声
  - 宽带噪声
- 热迟滞 Thermal Hysteresis
- 长期稳定性 Long Term Stability
  - **Long-Term Drift (LTD)**
  - **Early-Life Drift (ELD)**
- 电压调整率（Line Regulation）
- 负载调整率 （Load Regulation）
- 输入输出电压差（压差）（ Dropout Voltage ）

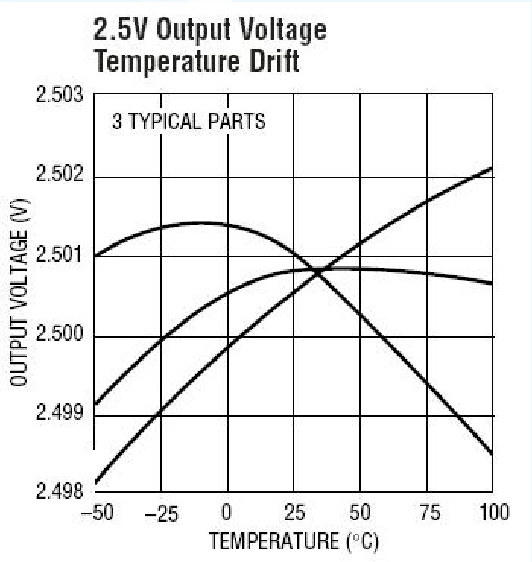


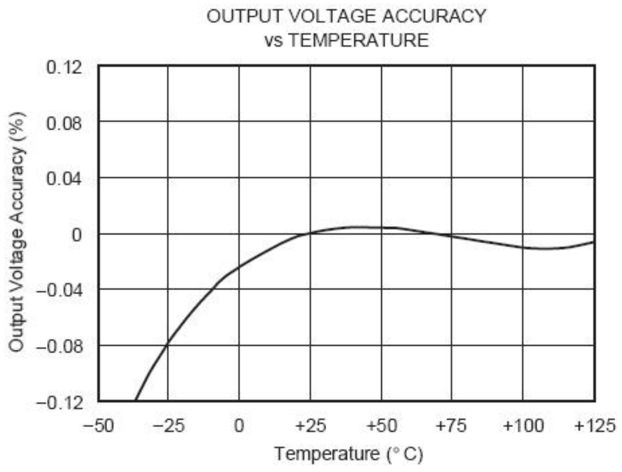


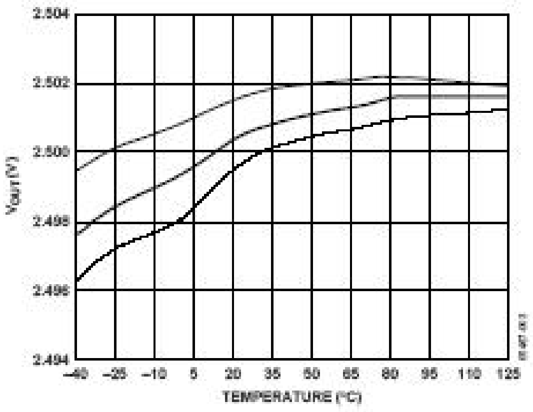
温度漂移（温度系数）特性

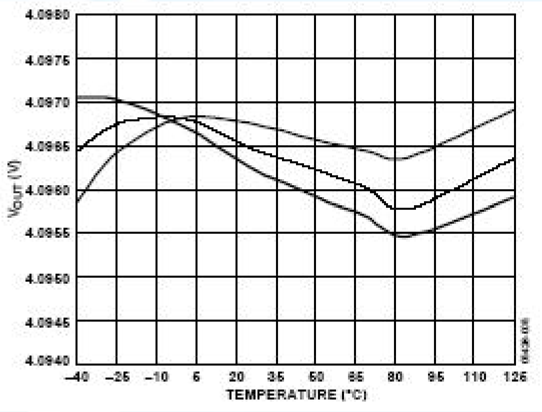

2.5V Reference Voltage
vs Temperature
TEMPCO –60°C TO 120°C
3 TYPICAL PARTS
REFERENCE VOLTAGE (V)
2.5020
2.5015
2.5010
2.5005
2.5000
2.4995
2.4990
2.4985
2.4980
–60 –40 –20 0 20 40 60 80 100 120
TEMPERATURE (°C)


2.5V Output Voltage
Temperature Drift
3 TYPICAL PARTS
REFERENCE VOLTAGE (V)
2.5010
2.5005
2.5000
2.4995
2.4990
2.4985
–50 –25 0 25 50 75 100 125 150
TEMPERATURE (°C)

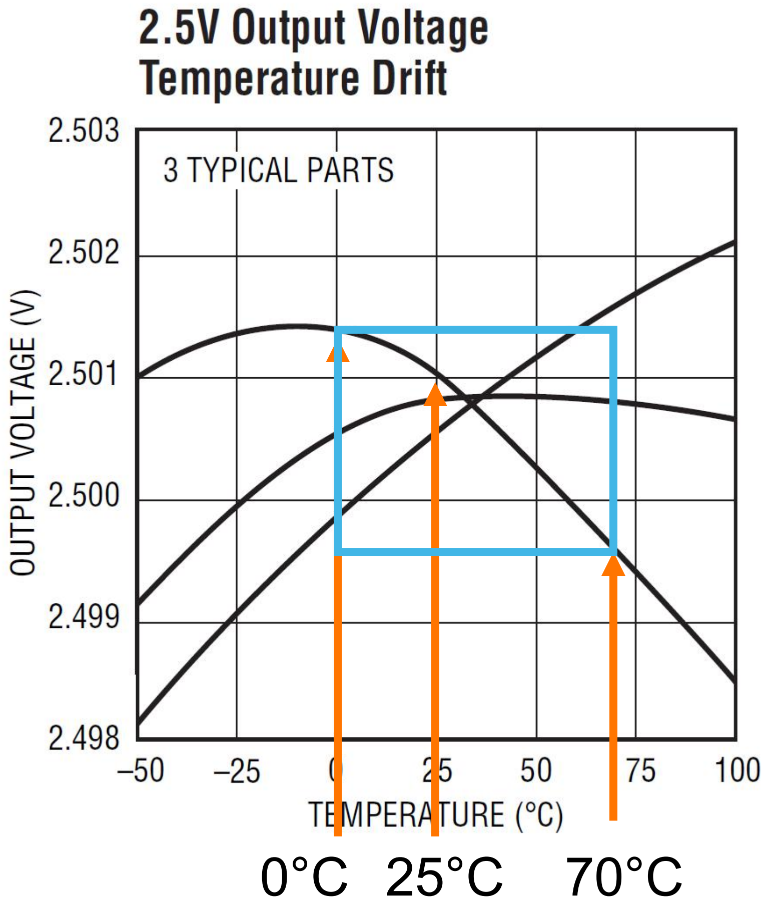

2.5V Output Voltage
Temperature Drift
3 TYPICAL PARTS
OUTPUT VOLTAGE (V)
2.503
2.502
2.501
2.500
2.499
2.498
–50 –25 0 25 50 75 100
TEMPERATURE (°C)

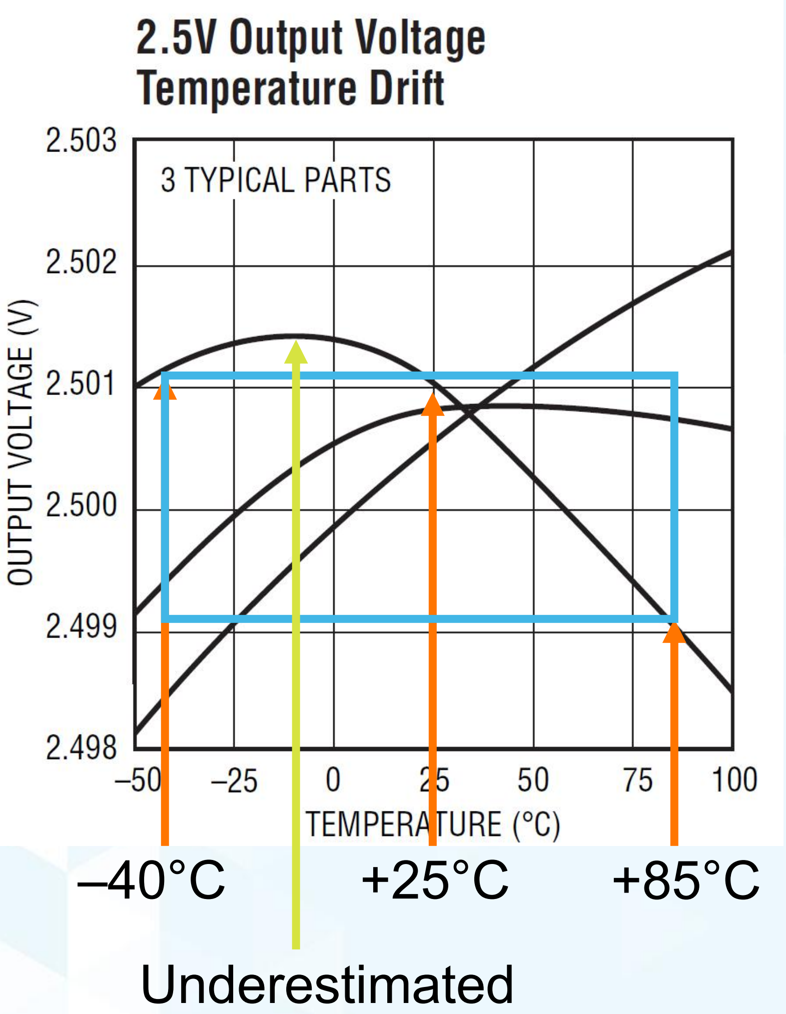

OUTPUT VOLTAGE ACCURACY
vs TEMPERATURE
Output Voltage Accuracy (%)
0.12
0.08
0.04
0
–0.04
–0.08
–0.12
–50 –25 0 +25 +50 +75 +100 +125
Temperature (° C)


V_{OUT} (V)
2.504
2.502
2.500
2.498
2.496
2.494
–40 –25 –10 5 20 35 50 65 80 95 110 125
TEMPERATURE (°C)


V_{OUT} (V)
4.0980
4.0975
4.0970
4.0965
4.0960
4.0955
4.0950
4.0945
4.0940
–40 –25 –10 5 20 35 50 65 80 95 110 125
TEMPERATURE (°C)

温度系数的典型测量方法: Box Method





温度系数测量方法: Box Method vs Bow-tie Method

Box Method

The box method is represented by the following equation:

$$TCV_{OUT} = \left| \frac{max\{V_{OUT}(T_1,T_2,T_3)\} - min\{V_{OUT}(T_1,T_2,T_3)\}}{V_{OUT}(T_2) \times (T_3 - T_1)} \right| \times 10^6$$

where:

TCV_{OUT} is expressed in ppm/°C.

$V_{OUT}(Tx)$ is the output voltage at Temperature Tx.

$T_1 = -40°C$.

$T_2 = +25°C$.

$T_3 = +125°C$.

This box method ensures that TCV_{OUT} accurately portrays the maximum difference between any of the three temperatures at which the output voltage of the device is measured.

Bowtie Method

The bowtie method is represented by the following equation:

$$TCV_{OUT} = |max\{TCV_{OUT1}, TCV_{OUT2}\}|$$

where:

$$TCV_{OUT1} = \left| \frac{max\{V_{OUT}(T_1,T_2)\} - min\{V_{OUT}(T_1,T_2)\}}{V_{OUT}(T_2) \times (T_2 - T_1)} \right| \times 10^6$$

$$TCV_{OUT2} = \left| \frac{max\{V_{OUT}(T_2,T_3)\} - min\{V_{OUT}(T_2,T_3)\}}{V_{OUT}(T_2) \times (T_3 - T_2)} \right| \times 10^6$$

TCV_{OUT} is expressed in ppm/°C.

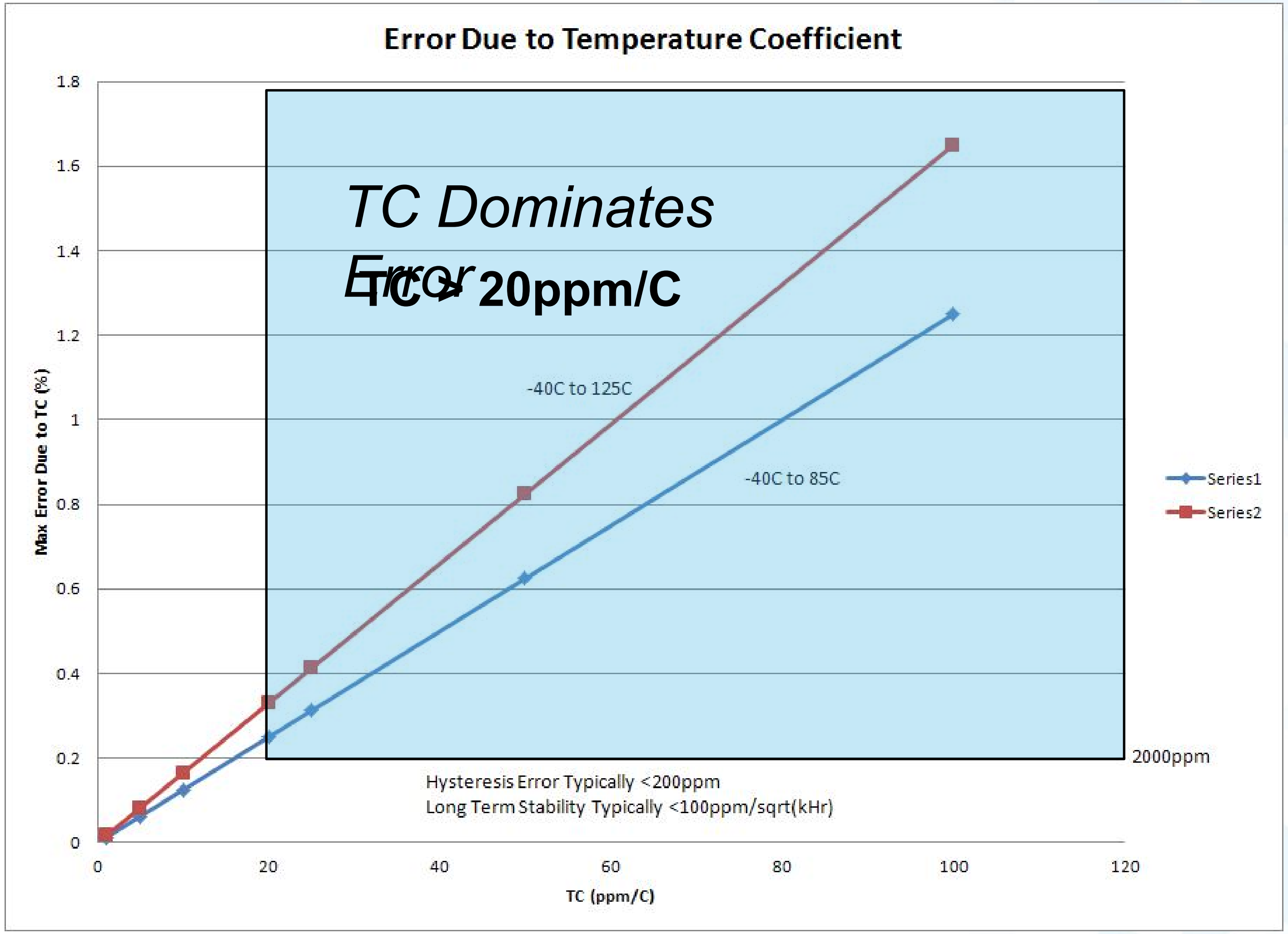
$V_{OUT}(Tx)$ is the output voltage at Temperature Tx.

$T_1 = 0°C$.

$T_2 = +25°C$.

$T_3 = +70°C$.

温度漂移性能的相对重要性



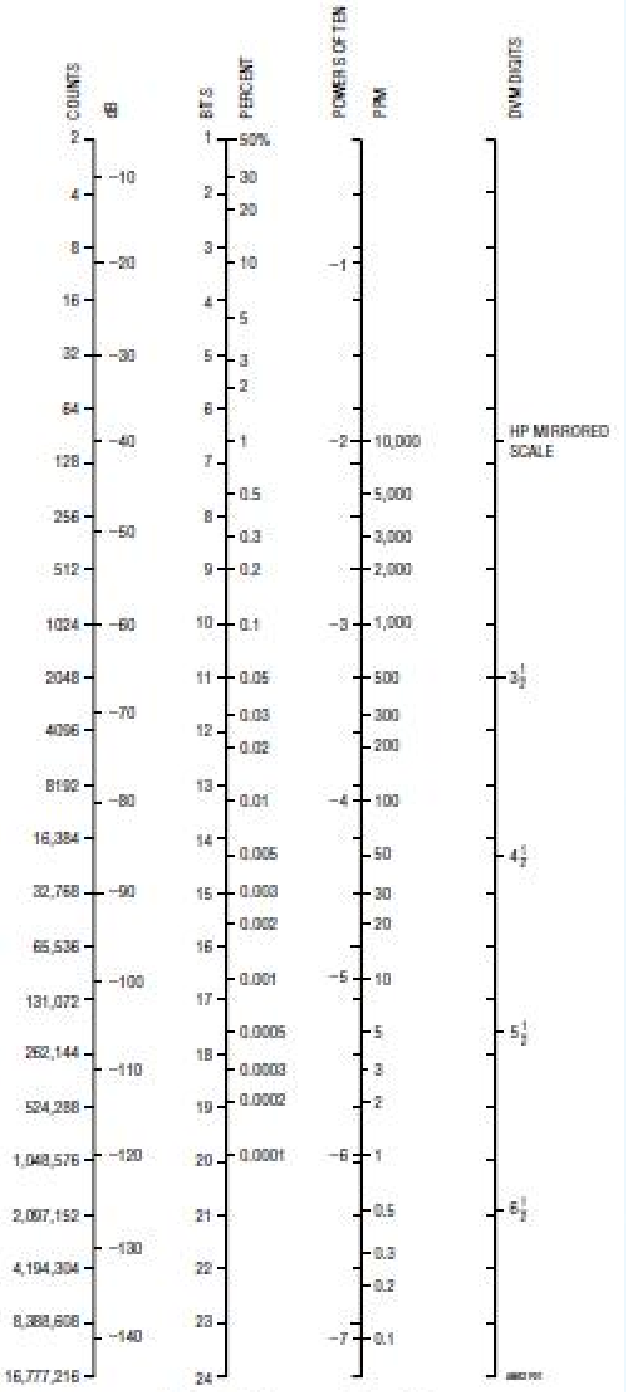


Figure 1. Accuracy Translator

如何选择一个合适的电压基准源

系统架构

- 电源电压
- 功率预算
- 负载能力
- 压差
- 温度范围
- 电路拓扑结构
- 特殊行业认证
- 封装尺寸
- 价格
- ……

切合系统性能要求的产品的误差性能

- 误差估算

  Total Error

  = Initial Accuracy
  + TC * (Total Specified Temp Range)
  + Line Regulation * (Application Vin – Specified Vin)
  + Load Regulation * (Iout)
  + Long Term Drift * √kHr
  + Thermal Hysteresis
  + Noise
  + Humidity Drift
- 对高精度ADC/DAC的驱动性能
- ……

电压基准源简单的选择路径图

ANALOG DEVICES
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LT6654 – "Go To" Vref

10 ppm/°C
38V Supply Range
±10 mA Iout
Low Noise
SOT23

Precision Instrumentation,
Vehicle Electrification

Highest Precision and Stability/Lowest Noise

- ADR4550 – 2 ppm/°C
- LTC6655 – 2 ppm/°C
- LTC6657 – 1.5 ppm/°C
- LTZ1000 – 1 ppm/°C

Medical/healthcare,
Gas Detection

Lowest Input Power

- ADR3550 – 100 μA
- ADR3450 – 100 μA
- LT1790 – 70 μA
- LT1461 – 60 μA
- REF195 – 45 μA
- ADR5045 – 10 μA
- LT6656 – 1 μA

Automotive
Solutions

Automotive (RTA qualified)

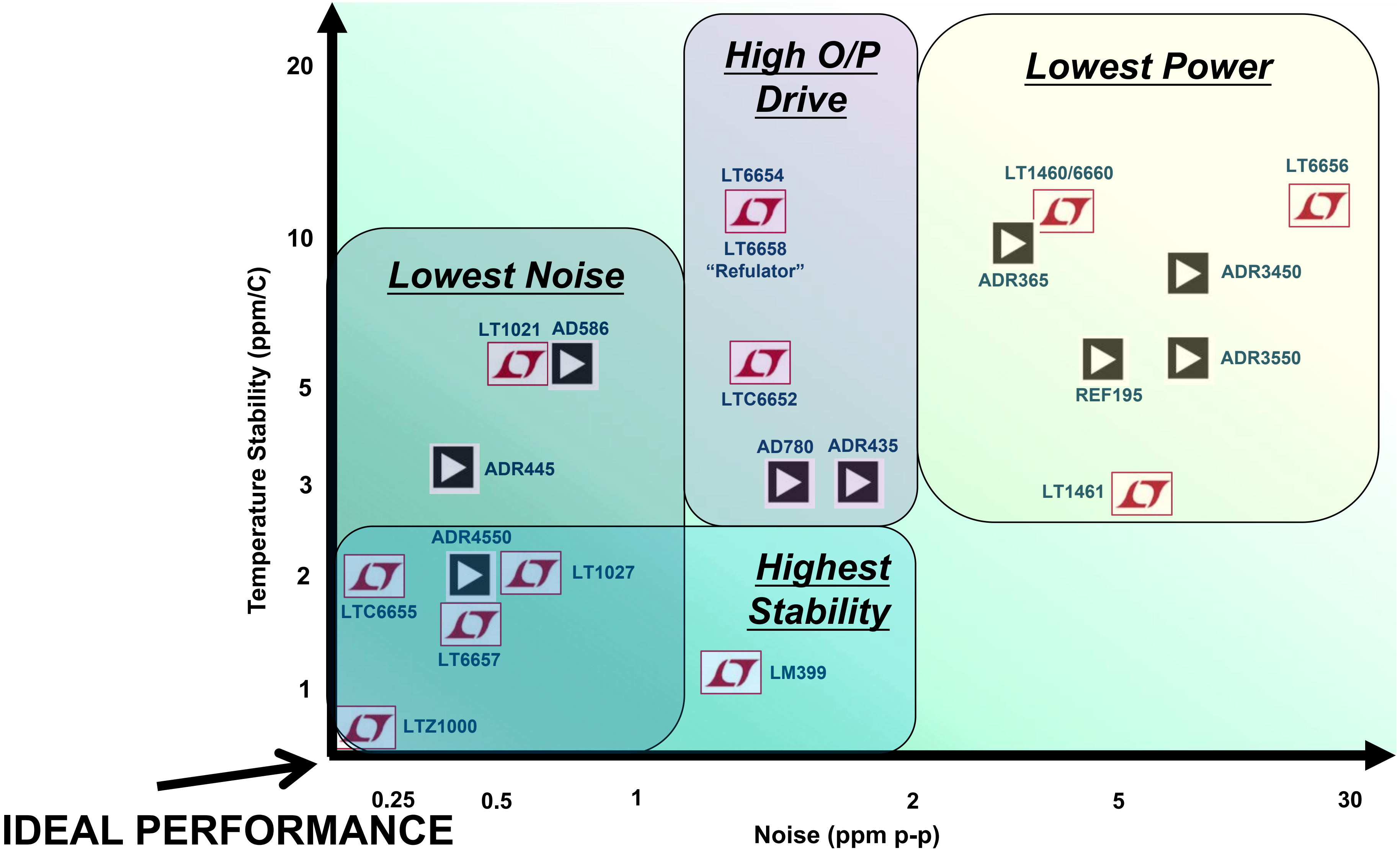
ADR4550	ADR3550
ADR365	LT6657
LT6654	LT1461
ADR5045	

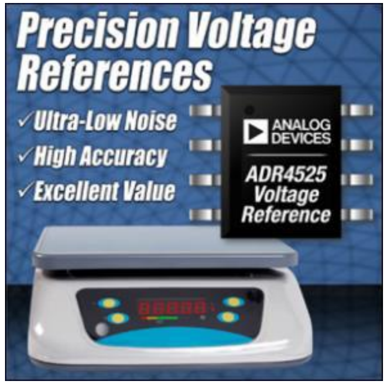
General Instrumentation
Autonomous Driving,
Compact Systems

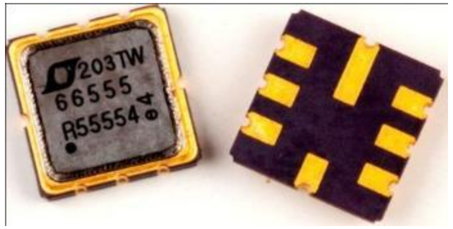
Highest Output Power

- LT1460 – 20 mA
- REF195 – 30 mA
- LT1461 – 50 mA
- LT6658 – 50 mA/150 mA

ADI – 业界产品系列最全、种类最多、性能最高的电压基准源供应商







LEADING EDGE

DRIFT PERFORMANCE

70 PPM to 10 PPM

ADR430/ADR431/ADR433/ADR434/ADR435 - 超低噪、强驱动电压基准源

Features and Specifications

- High accuracy
  - Voltage drift: 3 ppm/°C max (B grade)
  - Low initial output voltage error: 0.05% max (B grade)
  - Long term drift: <40 ppm/first 1 kHr typical
  - 1/f noise: 1.5 ppm, p-p (0.1 Hz to 10 Hz) typical
- Strong output
  - Output drive: +30/–20 mA
  - Load regulation: 15 ppm/mA max
- Versatility
  - Trim pin for fine adjustment
  - Comp pin for adjustment when driving cap loads
  - Input voltage range: up to 18 V
  - Quiescent current: 800 μA max
  - –40°C to +125°C operation
  - 2.048 V, 2.5 V, 3 V, 4.096 V, and 5 V outputs available
- Applications
  - Precision data acquisition systems
  - Medical, industrial, and test instrumentation
  - Automotive HEV and EV battery
  - Weigh scales and scientific equipment

Portfolio Positioning

Product Features	ADR43x	ADR44x
Low TC (temperature coefficient)	B Grade: 3 ppm/°C max at –40°C to +125°C	B Grade: 3 ppm/°C max at –40°C to +125°C
Output Drive	+30/–20 mA	+10/–50 mA
Load Regulation	15 ppm/mA max	50 ppm/mA max
Supply Current	800 μA max	3750 μA max

Competitive Positioning

Product Features	ADR43x	Competior
Low TC (Temperature Coefficient)	B Grade: 3 ppm/°C max at –40°C to +125°C	3 ppm/°C max at –40°C to +85°C
Output Drive	+30/–20 mA	±10 mA
Load Regulation	15 ppm/mA max	10 ppm/mA max
Supply Current	950 μA max	725 μA max

ADR4550/ADR4540/ ADR4533/ADR4530/ ADR4525/ADR4520:
- 超低噪、低温漂、超低功耗电压基准源

ANALOG DEVICES
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Features and Specifications

- High accuracy
  - Voltage drift: 2 ppm/°C max (B grade)
  - Low initial output voltage error: 0.02% max (B grade)
  - Long term drift: <25 ppm/first 1 kHr typical
- Excellent noise performance
  - 1/f noise: 0.5 ppm, p-p (0.1 Hz to 10 Hz) typical
- Versatility
  - Input voltage range: 3 V to 15 V
  - Low dropout: 300 mV for 2 mA at 125°C
  - Output drive: 10 mA
  - Quiescent current: 950 µA max
  - –40°C to +125°C operation
  - 2.048 V, 2.5 V, 3 V, 3.3 V, 4.096 V, and 5 V outputs available
- Applications
  - Medical, industrial, and test instrumentation
  - Automotive HEV and EV battery
  - Weigh scales and scientific equipment

Portfolio Positioning

Product Features	ADR45xx	ADR44x
Low TC (temperature coefficient)	B Grade: 2 ppm/°C max at –40°C to +125°C	B Grade: 3 ppm/°C max at –40°C to +125°C
Low 1/f Noise 0.1 Hz to 10 Hz	0.5 ppm, p-p typical	1.0 ppm, p-p typical
Supply Current	950 µA max	3750 µA max
Initial Voltage Output Error	B Grade: 0.02% max	B Grade: 0.05% max

Competitive Positioning

Product Features	ADR45xx	LTC6655B	Competitor
Low TC (temperature coefficient)	B Grade: 2 ppm/°C max at –40°C to +125°C	2 ppm/°C max at –40°C to +125°C	3 ppm/°C max at –40°C to +85°C
Low 1/f Noise 0.1 Hz to 10 Hz	0.5 ppm, p-p typical	0.25 ppm, p-p typical	0.6 ppm, p-p typical
Supply Current	950 µA max	7500 µA max	725 µA max
Initial Voltage Output Error	B: 0.02% max	0.025% max	0.02% max

ADR45xx新品: C级和D级产品

Key Features

- Ultra-High Accuracy
  - Voltage Drift: 2ppm/°C, max. (B Grade)
  - Low initial output voltage error: ±0.02% max. (B Grade)
  - Long Term Drift Grade A/B/C: < 25ppm/1st 1kHr. typ.
  - Long Term Drift Grade D: < 15ppm/1st 1kHr. typ.
- Excellent Noise Performance
  - 1/f noise: 0.5ppm,p-p (0.1Hz to 10Hz) typ.)
- Versatility
  - Input voltage range: 3V-15V
  - Low dropout: 300mV for +2mA at +125°C
    - 1V for ADR4520, 0.5V for ADR4525
  - Output drive: ± 10mA
  - Quiescent current: 950μA max.
- Wide Temperature Range
  - Grade A/B -40°C to +125°C operation

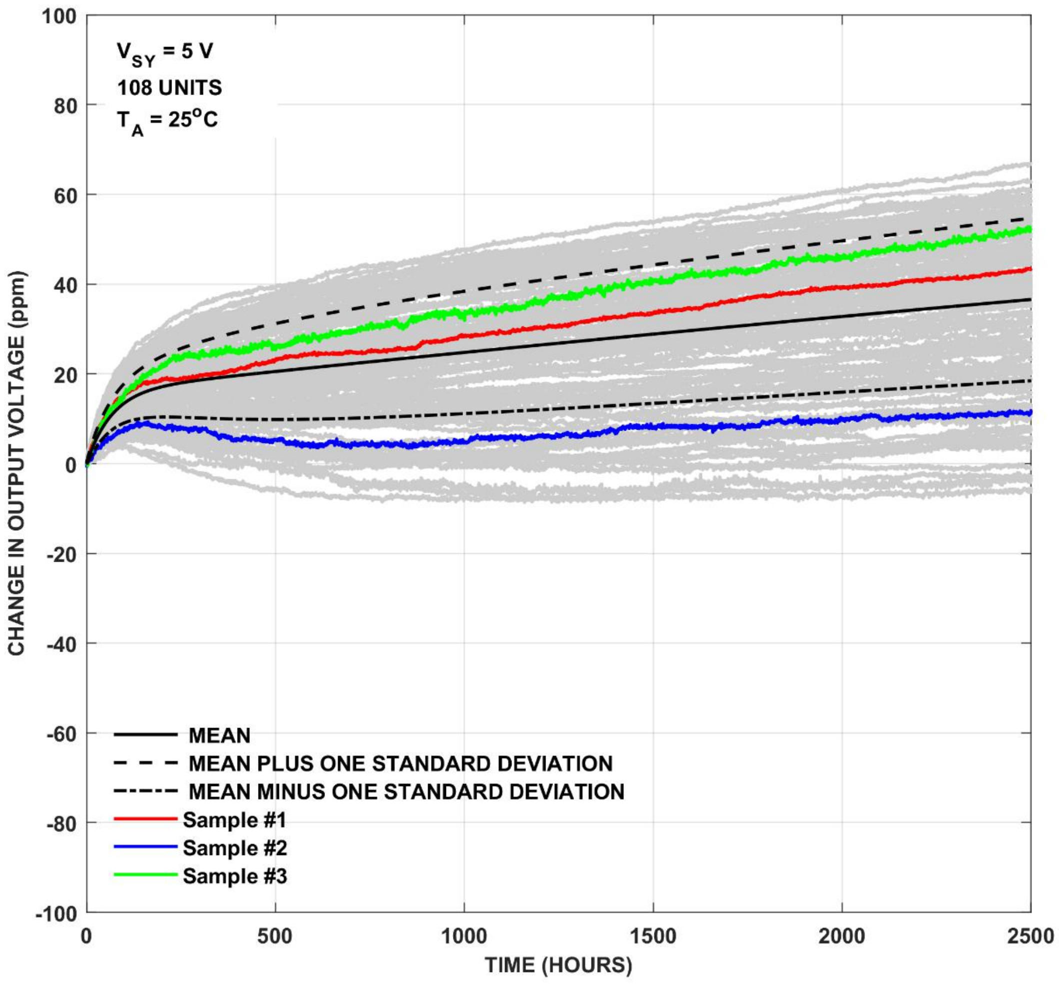
Applications

- Medical/Industrial/Test Instrumentation
- Automotive HEV & EV battery monitoring
- Weigh scales & Scientific Equipment

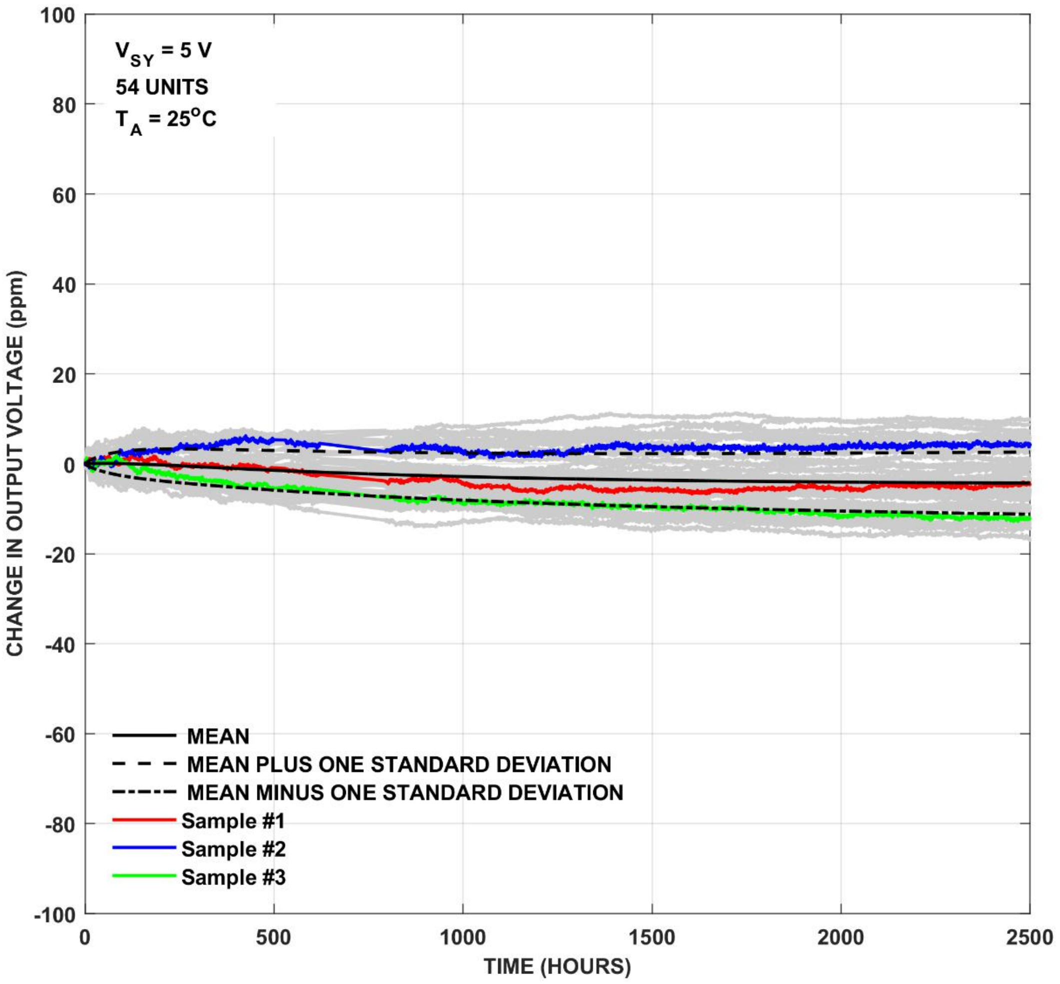
	Released		New Release	Sampling
	A - grade	B - grade	C - grade	D - grade
Temp Co (Box)	4 ppm/°C	2 ppm/°C	1 ppm/°C	0.5 ppm/°C
Temp Co (Bow Tie)	8 ppm/°C	4 ppm/°C	2 ppm/°C	1 ppm/°C
Initial Accuracy	0.04%	0.02%	0.02%	0.01%
Operating Temp Range	-40C to 125C	-40C to 125C	0C to 70C	0C to 70C
LTD (ppm/1st 1kHr typ)	<25	<25	<25	<15
Package	SOIC-8	SOIC-8	SOIC-8	LS-8

ADR45xx LTD: SOIC vs. LS8

SOIC



LS8



2019-7-29

LT6657: 宽工作电压、低压差、宽工作温度下业界最低温漂

ANALOG DEVICES
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Features and Specifications

- Low drift
  - A-Grade: 1.5 ppm/°C maximum
  - B-Grade: 3 ppm/°C maximum
- High accuracy
  - A-Grade: ±0.10% maximum
  - B-Grade: ±0.10% maximum
- Low noise: 0.5 ppm p-p (0.1 Hz to 10 Hz)
- Fully specified from –40°C to +125°C
- Applications
  - High temperature industrial
  - High resolution data acquisition systems
  - Instrumentation and process control
  - Automotive control and monitoring
  - Medical equipment
  - Shunt and negative voltage references

Portfolio Positioning

Product Features	LT6657	LTC6655
Temperature Coefficient	1.5 ppm/°C max	2 ppm/°C max
Supply Voltage	50 mV dropout to 40 V	500 mV dropout to 13.2 V
Load Regulation	6 ppm/mA maximum	30 ppm/mA maximum
Line Regulation	4 ppm/V maximum	40 ppm/V maximum

Competitive Positioning

Product Features	LT6657	Competitor
Temperature Coefficient	1.5 ppm/°C maximum	1.5 ppm/°C maximum
Supply Voltage	50 mV dropout to 40 V	8 V minimum supply for all voltage options
Load Regulation	6 ppm/mA maximum	7 ppm/mA maximum
Line Regulation	4 ppm/V maximum	35 ppm/V

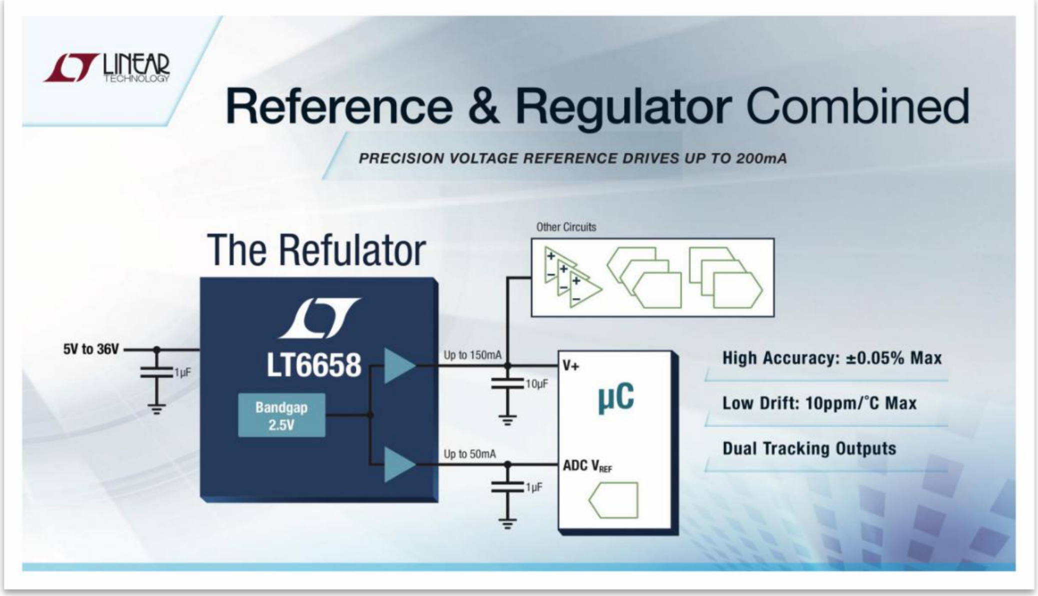
LT6658: 精密双通道输出、高驱动能力电压基准源

Features and Specifications

- Low drift
  - A-Grade: 10 ppm/°C Max
  - B-Grade: 20 ppm/°C Max
- High accuracy
  - A-Grade: ±0.215% Max
  - B-Grade: ±0.43% Max
- Low noise: 2.2 ppm p-p (0.1 Hz to 10 Hz, 5 V output)
- Fully specified from –40°C to +125°C
- Applications
  - Microcontroller or FPGA with ADC/DAC applications
  - Data acquisition systems
  - Automotive control and monitoring
  - Precision low noise regulators
  - Instrumentation and process control

Portfolio Positioning

Product Features	LT6658	LTC6654
Output Current	–20 mA to +150 mA/50 mA	±10 mA
Supply Voltage	2.5 V dropout to 36 V	100 mV dropout to 36 V
Load Regulation	1.67 ppm/mA maximum (150 mA output)	30 ppm/mA
Line Regulation	5 ppm/V maximum	10 ppm/V maximum



LTC6655LN: 业界最低噪的带隙电压基准源
0.25 ppm Noise, 2 ppm/°C Reference with Noise Reduction Pin

Features and Specifications

- Low noise
  - 0.21 ppm_{RMS} noise, 10 Hz to 1 kHz with C_{NR} = 100 µF
- High accuracy
  - B-grade: 0.025% initial accuracy, 2 ppm/°C temp coefficient
  - C-grade: 0.05% initial accuracy, 5 ppm/°C temp coefficient
- Fully specified from –40°C to +125°C
- Applications
  - Instrumentation and test equipment
  - High resolution data acquisition systems
  - Weigh scales and electric balance
  - Precision battery monitors
  - Precision regulators
  - Medical equipment

Portfolio Positioning

Product Features	LTC6655LN	LTC6655
RMS Noise (ppm RMS 10 Hz to 1 kHz)	0.21	0.67
Load Regulation	35 ppm/mA max	30 ppm/mA max
Noise Reduction Pin	Yes	No
Package	MSOP	MSOP, LS8

Competitive Positioning

Product Features	LTC6655LN	Competitor
RMS Noise (ppm RMS 10 Hz to 1 kHz)	0.21	2
Load Regulation	35 ppm/mA max	50 ppm/mA max
Noise Reduction Pin	Yes	Yes
Package	MSOP	MSOP

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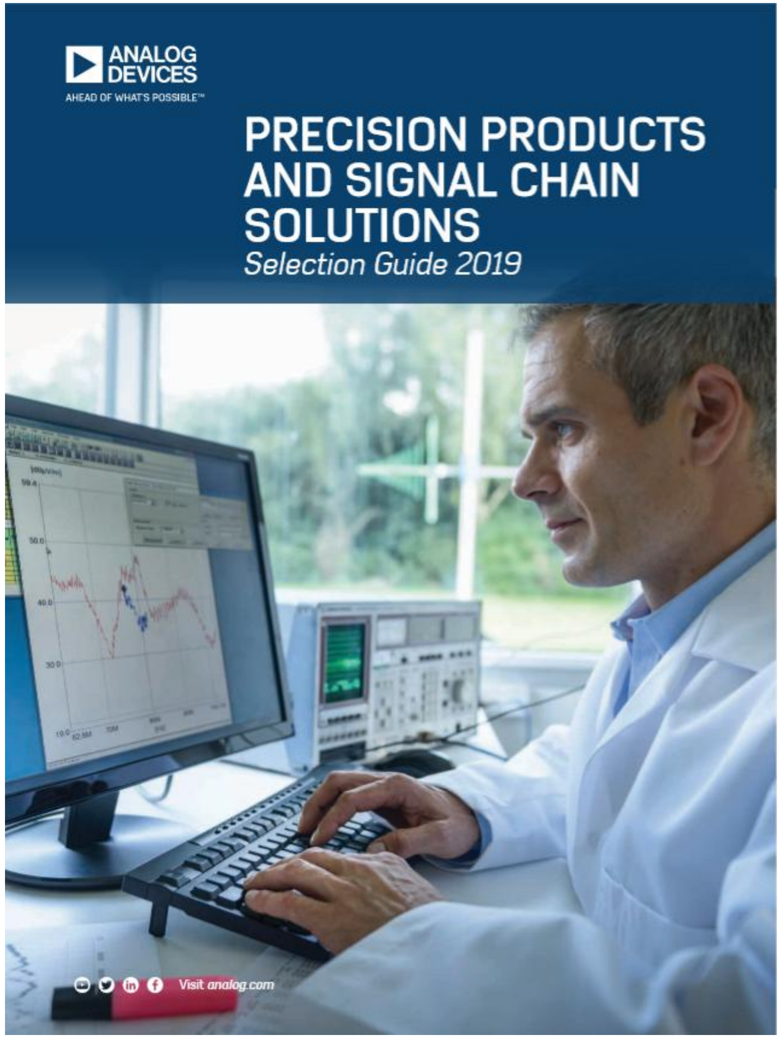

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