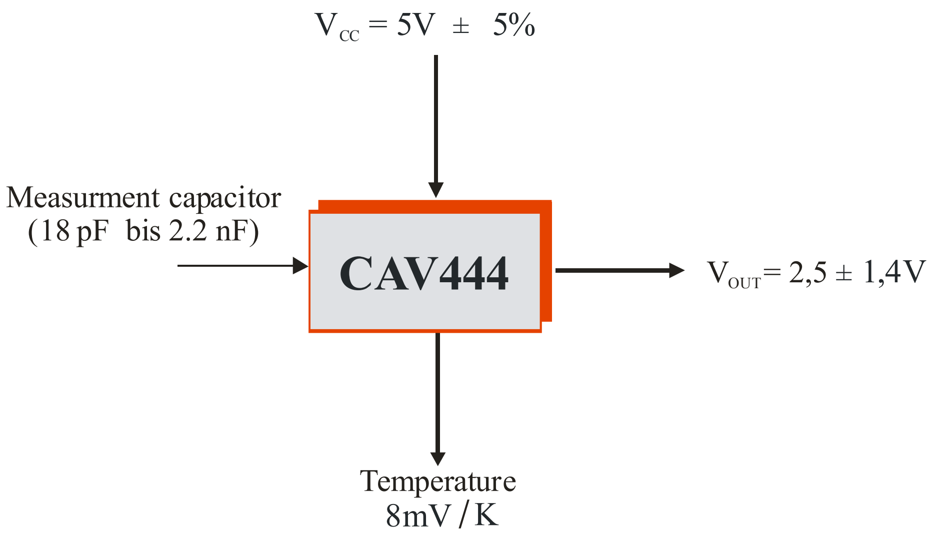
CAV444 – C/V transmitter IC with adjustable output voltage for capacitive input signals

PRINCIPLE FUNCTION

Capacitance/Voltage converter IC with an adjustable, differential output and temperature detection



Typical applications

CAV444 is an integrated capacitance-to-voltage transducer. The IC is particularly suitable for all measurements designed to convert a capacitive input signal into a voltage that is direct proportional to the change in the capacitance to be measured. It can be used for:

- **Measurement of humidity**
- **Level sensing**
- **Material identification**
- **Object detection**
- **The IC can be used as an input circuit for microprocessors or as a stand-alone IC**

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CONTENTS

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FEATURES

- Differential output signal
- Wide capacitor measuring range: 18 pF to 2.2 nF
- Linear transfer behavior
- Adjustable offset voltage
- Adjustable full-scale signal
- Detection frequency: 15 Hz to 1.9 kHz
- Measurement oscillator frequency: 1 kHz to 130 kHz
- Wide dynamic range detection
- Wide temperature range: -40°C...+85°C
- Simple calibration (Excel program)
- RoHS compliant

GENERAL DESCRIPTION

CAV444 is an integrated C/V transducer that contains full signal conditioning electronics for the linear conversion of capacitive input signals into a suitable differential output voltage. It also has an additional temperature detector. The output signal is proportional to the change in capacitance $\Delta C_M = C_{M,max} - C_{M,min}$.

A differential voltage referenced to internal reference voltage V_{REF} is generated as an output signal. This output voltage has been specially designed for connection to a following A/D converter.

As this is an analog circuit, its resolution are only limited by noise.

Together with the integrated temperature sensor of the CAV444 and a processor, electronically calibratable systems can be assembled.

A simple Excel software program eases the dimensioning of CAV444.

BLOCK DIAGRAM

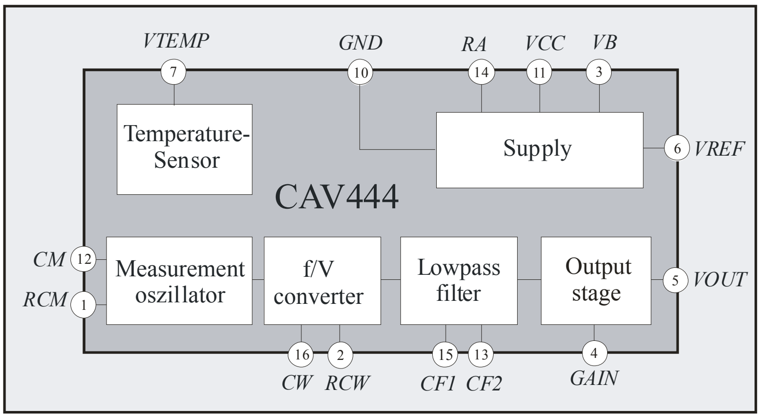

Figure 1: Block diagram of CAV444

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PRINCIPLE OF MEASUREMENT

CAV444 is an integrated C/V (capacitance-to-voltage) converter circuit that contains full signal conditioning and evaluation electronics for linear, capacitive signal sources.

The principle of measurement behind CAV444 is the conversion of a change in capacitance (measurement capacitor, C_M) into a linear, differential output voltage. Measurement capacitor C_M can be altered by the amount $\Delta C_M = C_{M,max} - C_{M,min}$ ($C_{M,min}$ is the basic capacitance of C_M).

HOW CAV444 WORKS

The CAV444 IC functions according to the following principle. The measurement capacitor is the capacitor of an internal measurement oscillator. This generates the clock pulse with which the measurement capacitor is charged and discharged. The number of clock pulses provided depends on the measurement capacitor. These are converted into a DC voltage signal in the f/V converter and in the backend lowpass filter. The filtered DC voltage signal travels to an adjustable amplifier stage that enables the output signal to be set to the required value.

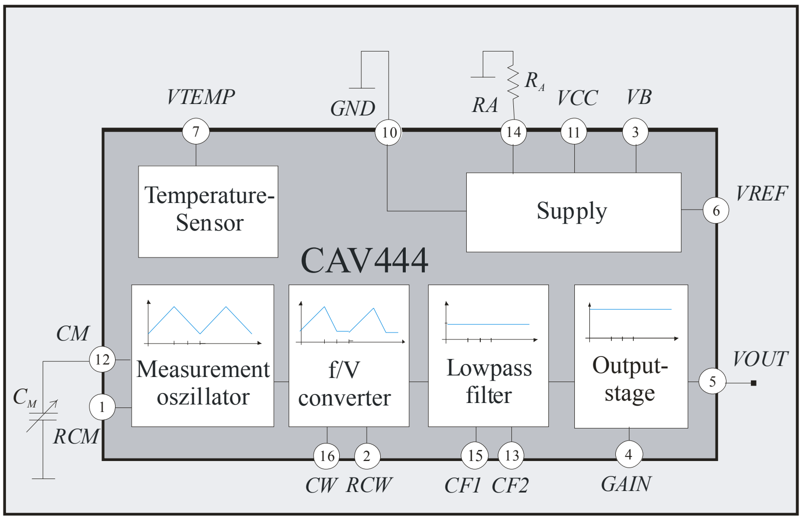

Figure 2: **Block diagram of CAV444 with signal patterns**

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TRANSFER FUNCTION (FULL-SCALE OUTPUT SIGNAL)

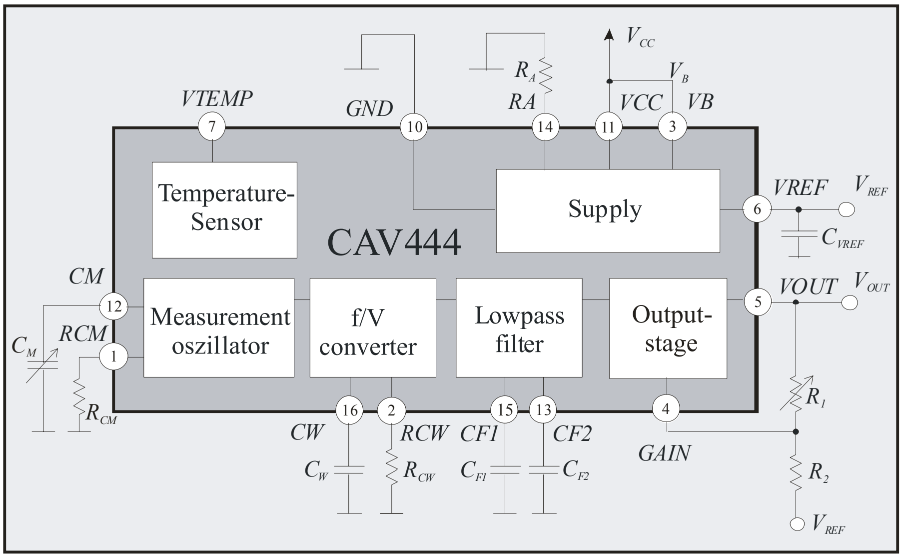

Figure 3: **CAV444 with circuitry for full-scale adjustment**

Transfer function V_{OUT*} for the CAV444 full-scale output signal is expressed as:

$$V_{OUT}* = V_{DIFF}* + V_{REF} \tag{1}$$

where V_{REF} = reference voltage and $V_{DIFF}* = G_{LP} \cdot V_{TPAS}$ (2)

The following applies to G_{LP}: $G_{LP} = 1 + \frac{R_1}{R_2}$ (3)

and to the output voltage after the lowpass: $V_{TPAS} = \frac{3 \cdot C_M \cdot \Delta V_{CM} \cdot R_{CM}}{8 \cdot C_W \cdot R_{CW}}$ (4)

with $\Delta V_{CM} = 2.1V$.

Equation (2) implies that signal V_{TPAS} is amplified by an internal operational amplifier in the output stage, where gain G_{LP} can be determined by resistors R_1 and R_2. Resistor R_A is used to set the supply for the f/V converter. Pin VB is for internal biasing and must be connected up to supply voltage V_{CC}.

With equations (3) and (4) incorporated into (2), the transfer function for the full-scale signal (1) is accrued as:

$$V_{OUT}* = V_{DIFF}* + V_{REF} = G_{LP} \cdot V_{TPAS} + V_{REF} = \left(1 + \frac{R_1}{R_2}\right) \cdot \left(\frac{3 \cdot C_M \cdot \Delta V_{CM} \cdot R_{CM}}{8 \cdot C_W \cdot R_{CW}}\right) + V_{REF} \qquad (5)$$

where $C_W = \frac{C_{M,\max}}{1.6}$. The resistors are defined by the respective load currents and have fixed values of R_{CM} = 250kΩ and R_{CW} = 500kΩ.

We can see that the output voltage is a linearly dependent function of measurable variable C_M ($V_{OUT*} = f(C_M)$), as all other variables are fixed by the dimensioning process.

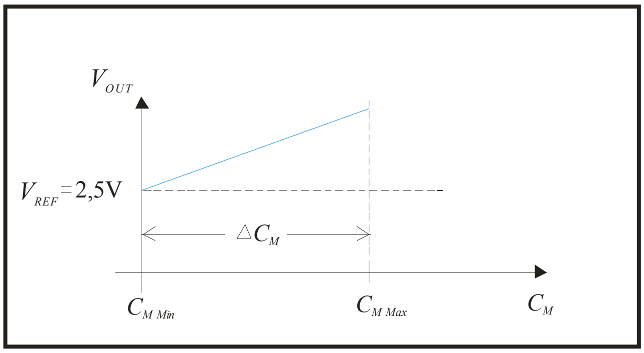

Figure 4: **Output signal V_{OUT*} referenced to ground**

In *Figure 4* we can recognize that the output signal is raised by V_{REF}. In order to be able to fix the offset, the network must be extended.

TRANSFER FUNCTION (WITH ADDITIONAL OFFSET ADJUSTMENT)

When setting the output signal the adjustability of the offset must be taken into account with the transfer function (5). With regard to *Figure 5*, the transfer function is calculated as:

$$V_{OUT} = V_{DIFF} + V_{REF} = A \cdot V_{TPAS} + B \cdot V_{REF} \qquad (6)$$

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with the setup coefficient for span as *A* and the setup coefficient for the offset *as B*:

$$A = \frac{R_4(R_2R_5 + R_1(R_2 + R_5)) + R_3((R_1 + R_2)R_4 + R_2R_5 + R_1(R_2 + R_5))}{R_2(R_4R_5 + R_3(R_4 + R_5))} \quad \text{and} \qquad (7)$$

$$B = \frac{(R_1 + 2R_2)R_4R_5 + R_3(2R_1R_2 + (R_1 + 2R_2)R_4 + R_1R_5 + 2R_2R_5)}{R_2(R_4R_5 + R_3(R_4 + R_5))} \qquad (8)$$

In the transfer equation resistors R_1 and R_3 used to set the span and offset are variable. They are calculated in the Excel program Kali_CAV444.xls. R_2, R_4 and R_5 are fixed 100kΩ resistors. We can see that the output voltage is a linearly dependent function of measurable variable C_M ($V_{OUT} = f(C_M)$), as all other variables are fixed by the dimensioning process and equation (5).

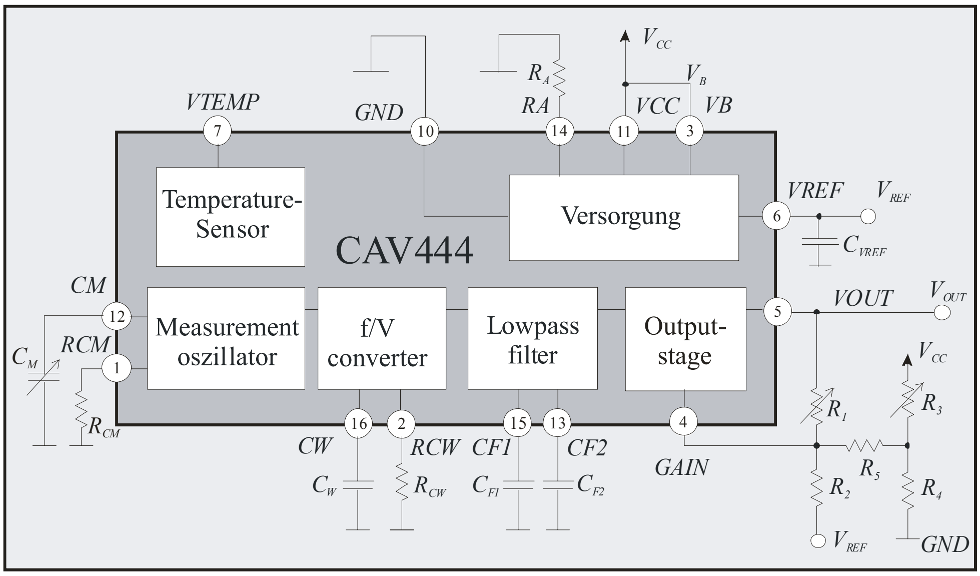

Figure 5: **Full circuit with adjustable full-scale output signal and adjustable offset signal**

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OUTPUT VOLTAGES

The following applies to the output voltage: $V_{OUT} = V_{DIFF} + V_{REF}$

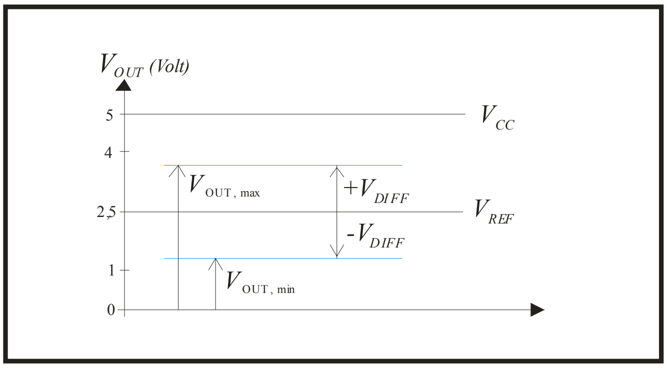

Figure 6: **Maximum output voltage VOUT**

THE DIMENSIONING PROCESS

Excel program Kali_CAV444.xls should be used for dimensioning purposes.

The dimensioning process for CAV444 assumes that in addition to measurement capacitor C_M and the f/V converter capacitor C_W, parasitic capacitances in both the IC and measurement circuit also influence the signal pattern.

For this reason the offset and full scale are calibrated based on the installed system, where all parasitic capacitances and exemplary variations in the components used have been taken into account.

Taking transfer function (6) as its basis, the Excel spreadsheet Kali_CAV444.xls [1] first computes suitable values for a measurement operating point. The circuit output is measured at this point and these measurements then entered into the program in stage two of the procedure. The algorithm calculates the two adjusting resistors required to calibrate the system. Once these have been placed in the circuit, the calibration of both offset and span is complete.

INITIAL OPERATION

Initial operation is described in detail in the description of the calibration program (see Kali_CAV444.xls).

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ELECTRICAL SPECIFICATIONS

T_{amb} = 25°C, V_{CC} = 5 V (unless otherwise stated)

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Unit
Supply						
Supply Voltage	V_{CC}	Ratiometric range	4.75	5.00	5.25	V
Quiescent Current	I_{CC}	T_{amb} = -40...+105°C, G_{LP} = 1	0.6	1.0	1.4	mA
Temperature Specifications						
Operating	T_{amb}		-40		105	°C
Storage	T_{st}		-55		125	°C
Measurement Oscillator						
Measurement Capacitor Range	C_M	$I_{CM} = 10\mu A$	18		2200	pF
Oscillator Frequency Range	f_M		1		130	kHz
Oscillator Current	I_{CM}	R_{CM} = 250kΩ	9.5	10	10.75	µA
Detection Frequency	f_{SIG}				1.9	kHz
f/V Converter						
Converter Capacitor Range	C_W	$C_W = C_{M,max} / 1.6$ $I_{CW} = 5\ \mu A$	11.25		1375	pF
Capacitive Charge Current	I_{CW}	R_{CW} = 500 kΩ	4.75	5	5.38	µA
Lowpass Stage						
Adjustable Gain	G_{LP}		1		10	
Output Voltage	V_{OUT}	$V_{out} = V_{Diff} + V_{REF}$	1.1		V_{CC} – 1.1	V
Corner Frequency 1	f_{CF1}	R_{01} = 20 kΩ, C_{F1} = 1 nF			8	kHz
Corner Frequency 2	f_{CF2}	R_{02} = 20 kΩ, C_{F2} = 1 nF			8	kHz
Resistive Load at pin V_{OUT}	R_L		200			kΩ
Capacitive Load at pin V_{OUT}	C_L				50	pF
Output Voltage Shift	V_{DIFF}	VM = 2.5 V	-1.4		1.4	V
Temperature Coefficient V_{DIFF} (together with Input Stages)	dV_{DIFF}/dT	T_{amb} = -40...+105°C		±100		ppm/°C
Internal Resistors 1 and 2	R_{01}, R_{02}			20		kΩ
Temperature Coefficient $R_{01,02}$	$dR_{01,02}/dT$	T_{amb} = -40...+105°C		1.9		10^{-3}/°C
Ratiometric Error of V_{OUT}	$RAT@V_{DIFF}$*			0.11		% FS
Voltage Reference V_{REF}						
Voltage	V_{REF}	Ratiometric to V_{CC}		2.5		V
V_{REF} vs. Temperature	dV_{REF}/dT	T_{amb} = -40...+105°C		±20	±50	ppm/°C
Current	I_{VREF}	Source			16	µA
	I_{VREF}	Sink			-16	µA
Load Capacitance	C_{VREF}		80	100	120	nF
Ratiometric Error of V_{REF}	$RAT@V_{REF}$*			0.007		% FS

* ***RAT @ V_{DIFF}*** = 2 [1.05 $V_{DIFF}(V_{CC}$ = 5V) – $V_{DIFF}(V_{CC}$ = 5.25V)]/[$V_{DIFF}(V_{CC}$ = 5V) + $V_{DIFF}(V_{CC}$ = 5.25V)]
** *RAT @ V_M* = 2 [1.05 $V_M(V_{CC}$ = 5V) – $V_M(V_{CC}$ = 5.25V)]/[$V_M(V_{CC}$ = 5V) + $V_M(V_{CC}$ = 5.25V)]

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Unit
Temperature Sensor V_{TEMP}						
Voltage	V_{TEMP}	$R_{TEMP} \geq 50$M□	2.20	2.32	2.45	V
Sensitivity	dV_{TEMP}/dT	$R_{TEMP} \geq 50$M□		8		mV/°C
Thermal Nonlinearity		$R_{TEMP} \geq 50$M□, end point method		0.5		% FS

***Table 1*: Electrical specifications for CAV444**

Notes:
1) Currents flowing into the IC are negative.
2) R_{TEMP} is the minimum possible load resistance at pin *VTEMP*.

In order to achieve as good a temperature behavior as possible, it is essential that resistors R_{CM} and R_{CW} have the same temperature coefficients and that they are placed very close together in the circuit.

STANDARD DIMENSIONING

Parameter	Symbol	Min.	Typ.	Max.	Unit
Output Stage Resistors (1%)	R_2 , R_4 , R_5		100		kΩ
Full-Scale Resistor (0.1%), Calibration Start Value*	R_1		33		kΩ
Offset Resistor (0.1%), Calibration Start Value*	R_3		100		kΩ
f/V-Stage Biasing Resistor	R_A		240		kΩ
Measurement Oscillator Resistor	R_{CM}		250		kΩ
f/V-Stage Filter Resistor	R_{CW}		500		kΩ
Filter Capacitors (vary with value of $C_{M,min}$)**	C_{F1} ,C_{F2}	3.8		440	nF
Reference Voltage Capacitor (V_{REF} = 2.5V)	C_{VREF}	80	100	120	nF

***Table 2:* Standard values for external components**

- *) R_1 and R_3 are the initial values given at the start of the calibration process (Kali_CAV444.xls). During calibration, these are replaced by precisely computed, individual values.
- **) C_{F1} and C_{F2} are dimensioned by the calibration program.

BOUNDARY CONDITIONS

Parameter	Symbol	Condition	Min.	Typ.	Max.	Unit
Maximum Supply Voltage	V_{CCmax}				17	V
Oscillator Frequency Range	f_{OSC}		1		130	kHz
f/V Converter Current	I_{CW}	R_{CW} = 500 kΩ			5.38	µA
Measurement Oscillator Current	I_{CM}	R_{CM} = 250 kΩ			10.75	µA

***Table 3:* Boundary conditions**

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APPLICATIONS

Example applications are generated by dimensioning the circuit in *Figure 5* with the help of the calibration program Kali_CAV444.xls [1]

BLOCK DIAGRAM AND PINOUT

PIN	NAME	DESCRIPTION
1	*RCM*	Current setting for the measurement oscillator
2	*RCW*	Current setting for the f/V converter
3	*VB*	Bias voltage → V_{CC}
4	*GAIN*	Gain setting
5	*VOUT*	Output voltage
6	*VREF*	Reference voltage 2.5 V
7	*VTEMP*	Temperature sensor output
8	*N.C.*	Not connected
9	*N.C.*	Not connected
10	*GND*	IC ground
11	*VCC*	Supply voltage
12	*CM*	Measurement capacitor/measurement oscillator capacitor
13	*CF2*	Lowpass capacitor 2, corner frequency 2
14	*RA*	Stabilizing resistor for f/V converter
15	*CF1*	Lowpass capacitor 1, corner frequency 1
16	*CW*	f/V converter capacitor

***Table 4*: CAV444 Pin out**

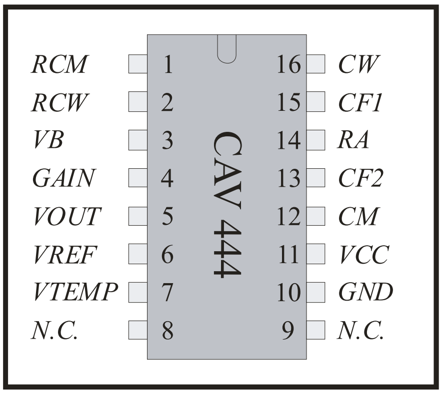

***Figure 10:* CAV444 Pin out**

DELIVERY

CAV444 is available as:

- An SO16 (n); see data sheets: package
- For sample batches CAV444 can be supplied on a DIL16 SO16 adapter (CAV444Adapt)

Package dimensions: see http://www.analogmicro.de/products/analogmicro.de.en.package.pdf

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ADDITIONAL EQUIPMENT

For design purposes, by way of support Analog Microelectronics can also supply a starter kit which consists of a breadboard (**BBCAV444**) (which has been assembled for a specific set of parameters but which can also be used for individual measurements), a description and the spreadsheet Kali_CAV444.

FURTHER READING

Please see our website for further information (www.analogmicro.de):

[1] http://www.analogmicro.de/english/index.html - Kali_CAV444.pdf

NOTES

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