[1]ETUDE DU CAPTEUR DE TEMPERATURE INTEGRE AD 590 H

Le schéma simplifié du capteur AD590H est donné en figure 1. Alimenté sous une tension constante V_{CC}, ce dispositif fait circuler un courant I proportionnel à la température T_j de la puce.

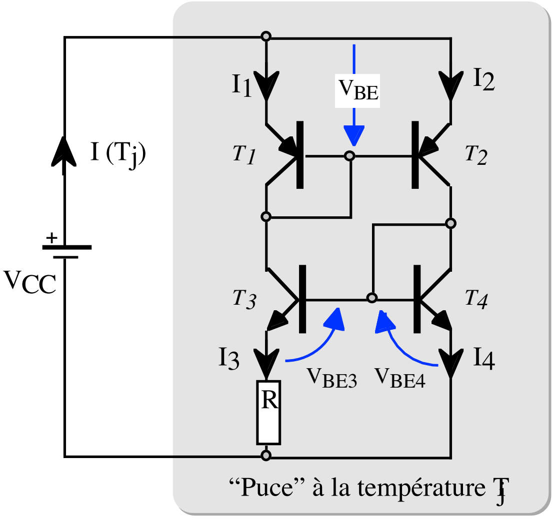

Figure 1

Les transistors PNP T_1 et T_2, identiques forment un miroir de courant simple. Ils ont le même gain en courant β_p et le même courant inverse de saturation de la jonction base collecteur entraînant alors : $I_{SBC1} = I_{SBC2}$. Par contre, les transistors NPN identiques, T_3 et T_4, bien que possédant le même gain en courant β_n sont construits avec une surface d'émetteur S_E telle que : $S_E(T_3) = n\, S_E(T_4)$ de telle sorte que : $I_{SBC3} = nI_{SBC4} \quad n > 1$

Tous les transistors obéissent à la loi : $I_C = I_{SBCi} \exp\left(\dfrac{|V_{BE}|}{U_T}\right)$ *(1)* $\qquad U_T = \dfrac{kT}{q}$ *(2)*

k : constante de Boltzmann, q : charge élémentaire ,T : température absolue.

1°PARTIE : ETUDE ELECTRIQUE

1. Montrer que les courants I_1 et I_2 sont rigoureusement identiques.

2. Dans la mesure où le gain en courant des transistors est assez important, montrer que l'on peut écrire : $I_1 = I_2 = I_3 = I_4$.

3. En exploitant l'équation (1), chercher une autre relation entre les courants I_3 et I_4.

4. Déduire des relations précédentes que le courant I de l'alimentation V_{CC} est proportionnel à la température T_j de la puce : $I(T_j) = \left[\dfrac{2k}{qR}\ln(n)\right] T_j$. Rechercher dans la documentation du

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[1] Philippe ROUX © 2006 http://rouxphi3.perso.cegetel.net

constructeur, la valeur du coefficient de proportionnalité α ainsi que le domaine de température de fonctionnement du capteur AD 590H.

2°PARTIE : ETUDE THERMIQUE

*Le capteur dans son boîtier (**type H** dont la résistance thermique n'est pas nulle), est placé dans un milieu à température ambiante T_a. Le schéma du circuit thermique équivalent est donné par le constructeur sur le document annexe (figure 8). On peut en première approximation représenter ce schéma par le circuit du premier ordre de la figure 2.*

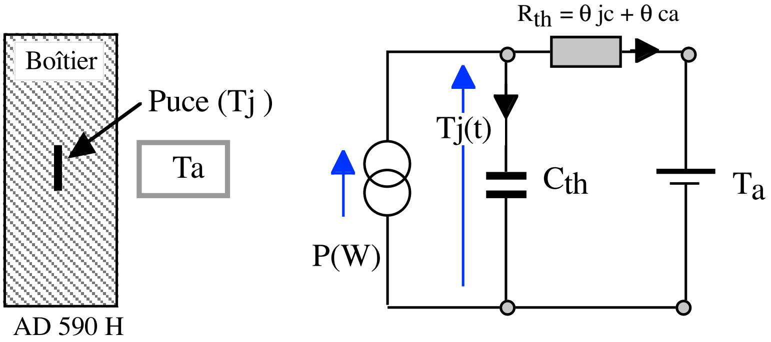


Figure 2

A l'instant initial, on alimente la puce sous une tension continue V_{CC} de 10 V afin de mesurer la température T_a.

1. Déterminer l'expression du flux de chaleur P.

2. Compte tenu du schéma thermique de la figure 2, en faisant le bilan des flux de chaleur, écrire l'équation différentielle qui permet de déterminer la température $T_j(t)$ de la puce du capteur. On posera : $a = \alpha V_{CC}$.

3. Résoudre l'équation différentielle (séparer les variables t et T_j (t), intégrer sans oublier la constante d'intégration qui dépend des conditions initiales). Quelle est l'expression de la constante de temps τ ?

4. D'après les données du constructeur du tableau I (boîtier H, still air without heat sink), quelles valeurs doit-on attribuer à la résistance thermique jonction- ambiante et à la constante de temps τ. Calculer le coefficient αV_{CC}.

5. Au bout de combien de temps est-il possible de mesurer la température ambiante T_a ?
   - Quelle sera alors la température de la jonction T_j ?
   - En déduire l'erreur relative de mesure commise en %.

CORRECTION

1°PARTIE : ETUDE ELECTRIQUE

1. Le courant d'émetteur des transistors T_1 et T_2 sont tels que :

$$I_1 = I_{SBC1}\exp\left(\frac{|V_{BE1}|}{U_T}\right)\left(1+\frac{1}{\beta_p}\right) \qquad I_2 = I_{SBC2}\exp\left(\frac{|V_{BE2}|}{U_T}\right)\left(1+\frac{1}{\beta_p}\right)$$

Sachant que : $V_{BE1} = V_{BE2}$ et $I_{SBC1} = I_{SBC2}$, les courants I_1 et I_2 sont identiques.

2. Dans la mesure où le gain en courant des transistors est élevé, on peut assimiler le courant de collecteur avec le courant d'émetteur, aussi : $I_3 = I_4 = I_1 = I_2$.

3. Le courant de base étant négligeable, exprimons les courants I_3 et I_4 :

$$I_3 = I_{SBC3}\exp\left(\frac{|V_{BE3}|}{U_T}\right) \qquad I_4 = I_{SBC4}\exp\left(\frac{|V_{BE4}|}{U_T}\right)$$

$$\frac{I_3}{I_4} = \frac{I_{SBC3}}{I_{SBC4}}\exp\left(\frac{|V_{BE3}|-|V_{BE4}|}{U_T}\right) \qquad \text{->} \qquad 1 = n\exp\left(\frac{|V_{BE3}|-|V_{BE4}|}{U_T}\right)$$

sachant que : $V_{BE4} = V_{BE3} + RI_3$, il vient : $1 = n\exp\left(\frac{-RI_3}{U_T}\right)$

$$\boxed{I_3 = I_4 = \frac{kT_j}{qR}\ln(n)}$$

4. Le courant d'alimentation I est tel que : $I = I_3 + I_4 = I_1 + I_2$ et les courants I_i sont égaux. On peut donc écrire :

$$\boxed{I(T_j) = \left[\frac{2k}{qR}\ln(n)\right]T_j = \alpha T_j}$$

Le courant d'alimentation est proportionnel à la température de la puce. Le facteur de proportionnalité α est de 1µA/K dans une gamme : $-55°C < T_j < 150\ °C$.
La tension d'alimentation V_{CC} doit être comprise entre 4 et 30 V.

2°PARTIE : ETUDE THERMIQUE

1. Le flux de chaleur au niveau de la puce est tel que : $P(W) = V_{CC}(\alpha T_j)$ que l'on écrira sous la forme : $P(W) = K.T_j$.

2. Ecrivons l'équation au nœud : $\boxed{KT_j = C_{th}\frac{dT_j}{dt} + \frac{T_j - T_a}{R_{th}}}$

3. Séparons les variables, il vient alors : $-\frac{dt}{R_{th}C_{th}} = \frac{dT_j}{(1-KR_{th})T_j - T_a}$

Il convient alors d'intégrer et de déterminer la constante d'intégration avec la condition initiale : à t = 0 $T_j(0) = T_a$.

Solution :

$$\boxed{T_j(t) = \frac{T_a}{1 - KR_{th}} - \frac{KR_{th}T_a}{1 - KR_{th}}\exp(-\frac{t}{\tau})}$$

Constante de temps : $$\boxed{\tau = \frac{C_{th}R_{th}}{1 - KR_{th}}}$$

4. Les données du constructeur donnent les résultats suivants :
Constante de temps : $\tau = 60s$. Résistance thermique du boîtier : R_{th} = 480 °C/W.
On peut alors calculer le coefficient K : K = α V_{CC} = 10µW/°C.

5. A partir de 5τ soit un temps de 300 s, il est alors possible de lire la température T_j.qui a pour expression :

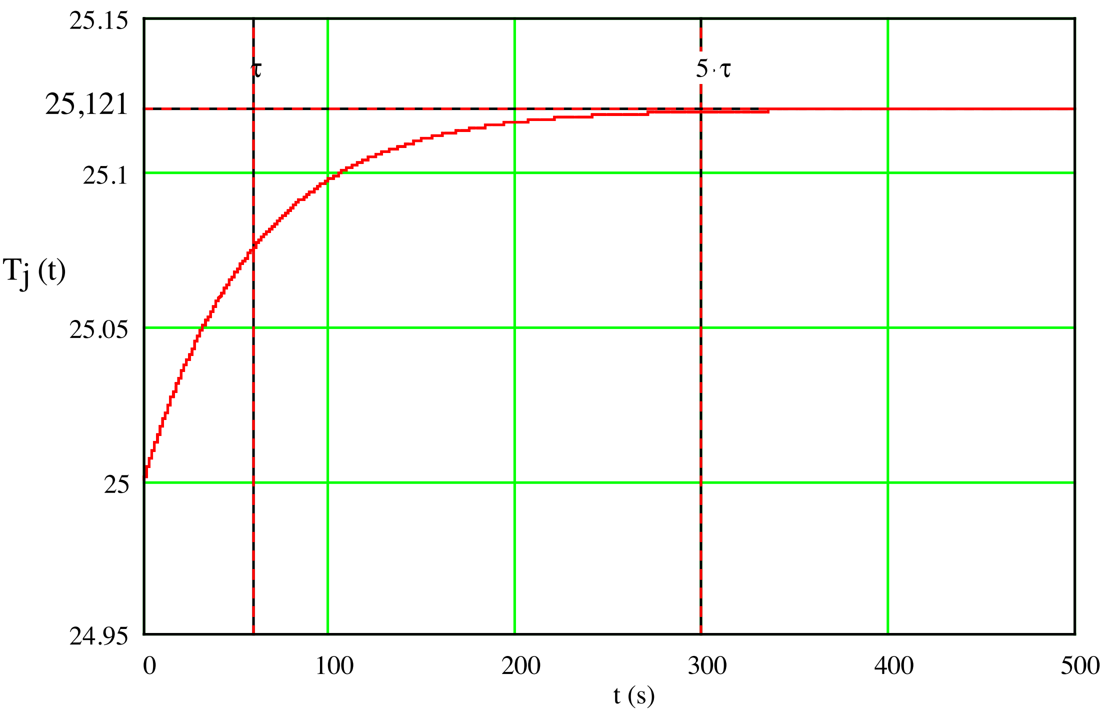
$$\boxed{T_j(\infty) = \frac{T_a}{1 - KR_{th}}}$$

$T_j(\infty)$ est évidemment supérieure à la température ambiante compte tenu de la présence du boîtier avec sa résistance thermique. On fait donc une erreur de mesure en effet :

$$\boxed{T_j(\infty) = \frac{T_a}{1 - KR_{th}} = 1{,}0048T_a}$$

soit une erreur relative de 0,48%.

Graphe de T_j (t) pour T_a = 25 °C :



ANALOG DEVICES

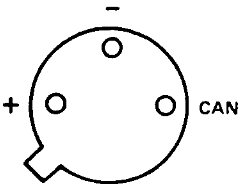
Two-Terminal IC Temperature Transducer

AD590*

FEATURES

- Linear Current Output: 1μA/K
- Wide Range: -55°C to +150°C
- Probe Compatible Ceramic Sensor Package
- Two-Terminal Device: Voltage In/Current Out
- Laser Trimmed to ±0.5°C Calibration Accuracy (AD590M)
- Excellent Linearity: ±0.3°C Over Full Range (AD590M)
- Wide Power Supply Range: +4V to +30V
- Sensor Isolation from Case
- Low Cost

AD590 PIN DESIGNATIONS



BOTTOM VIEW

PRODUCT DESCRIPTION

The AD590 is a two-terminal integrated circuit temperature transducer which produces an output current proportional to absolute temperature. For supply voltages between +4V and +30V the device acts as a high impedance, constant current regulator passing 1μA/K. Laser trimming of the chip's thin film resistors is used to calibrate the device to 298.2μA output at 298.2K (+25°C).

The AD590 should be used in any temperature sensing application below +150°C in which conventional electrical temperature sensors are currently employed. The inherent low cost of a monolithic integrated circuit combined with the elimination of support circuitry makes the AD590 an attractive alternative for many temperature measurement situations. Linearization circuitry, precision voltage amplifiers, resistance measuring circuitry and cold junction compensation are not needed in applying the AD590.

In addition to temperature measurement, applications include temperature compensation or correction of discrete components, biasing proportional to absolute temperature, flow rate measurement, level detection of fluids and anemometry. The AD590 is available in chip form making it suitable for hybrid circuits and fast temperature measurements in protected environments.

The AD590 is particularly useful in remote sensing applications. The device is insensitive to voltage drops over long lines due to its high impedance current output. Any well-insulated twisted pair is sufficient for operation hundreds of feet from the receiving circuitry. The output characteristics also make the AD590 easy to multiplex: the current can be switched by a CMOS multiplexer or the supply voltage can be switched by a logic gate output.

PRODUCT HIGHLIGHTS

1. The AD590 is a calibrated two terminal temperature sensor requiring only a dc voltage supply (+4V to +30V). Costly transmitters, filters, lead wire compensation and linearization circuits are all unnecessary in applying the device.
2. State-of-the-art laser trimming at the wafer level in conjunction with extensive final testing insures that AD590 units are easily interchangeable.
3. Superior interference rejection results from the output being a current rather than a voltage. In addition, power requirements are low (1.5mW's @ 5V @ +25°C). These features make the AD590 easy to apply as a remote sensor.
4. The high output impedance (>10MΩ) provides excellent rejection of supply voltage drift and ripple. For instance, changing the power supply from 5V to 10V results in only a 1μA maximum current change, or 1°C equivalent error.
5. The AD590 is electrically durable: it will withstand a forward voltage up to 44V and a reverse voltage of 20V. Hence, supply irregularities or pin reversal will not damage the device.

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*Covered by Patent No. 4,123,698

SPECIFICATIONS (@ +25°C and $V_S = 5V$ unless otherwise noted)

Model	AD590J Min	AD590J Typ	AD590J Max	AD590K Min	AD590K Typ	AD590K Max	Units
ABSOLUTE MAXIMUM RATINGS							
Forward Voltage (E+ to E−)			+44			+44	Volts
Reverse Voltage (E+ to E−)			−20			−20	Volts
Breakdown Voltage (Case to E+ or E−)			±200			±200	Volts
Rated Performance Temperature Range[1]	−55		+150	−55		+150	°C
Storage Temperature Range[1]	−65		+155	−65		+155	°C
Lead Temperature (Soldering, 10 sec)			+300			+300	°C
POWER SUPPLY							
Operating Voltage Range	+4		+30	+4		+30	Volts
OUTPUT							
Nominal Current Output @ +25°C (298.2K)		298.2			298.2		μA
Nominal Temperature Coefficient		1			1		μA/K
Calibration Error @ +25°C			**±5.0**			**±2.5**	°C
Absolute Error (over rated performance temperature range)							
Without External Calibration Adjustment			**±10**			**±5.5**	°C
With +25°C Calibration Error Set to Zero			**±3.0**			**±2.0**	°C
Nonlinearity			**±1.5**			**±0.8**	°C
Repeatability[2]			±0.1			±0.1	°C
Long Term Drift[3]			±0.1			±0.1	°C
Current Noise		40			40		pA/√Hz
Power Supply Rejection							
$+4V \leq V_S \leq +5V$		0.5			0.5		μA/V
$+5V \leq V_S \leq +15V$		0.2			0.2		μA/V
$+15V \leq V_S \leq +30V$		0.1			0.1		μA/V
Case Isolation to Either Lead		10^{10}			10^{10}		Ω
Effective Shunt Capacitance		100			100		pF
Electrical Turn-On Time		20			20		μs
Reverse Bias Leakage Current[4] (Reverse Voltage = 10V)		10			10		pA
PACKAGE OPTION[5]							
TO-52 (H-03A)		AD590JH			AD590KH		
Flat Pack (F-2A)		AD590JF			AD590KF		

NOTES

[1] The AD590 has been used at −100°C and +200°C for short periods of measurement with no physical damage to the device. However, the absolute errors specified apply to only the rated performance temperature range.

[2] Maximum deviation between +25°C readings after temperature cycling between −55°C and +150°C; guaranteed not tested.

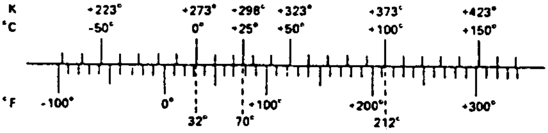
[3] Conditions: constant +5V, constant +125°C; guaranteed, not tested.

[4] Leakage current doubles every 10°C.

[5] See Section 16 for package outline information.

Specifications subject to change without notice.

Specifications shown in boldface are tested on all production units at final electrical test. Results from those tests are used to calculate outgoing quality levels. All min and max specifications are guaranteed, although only those shown in boldface are tested on all production units.

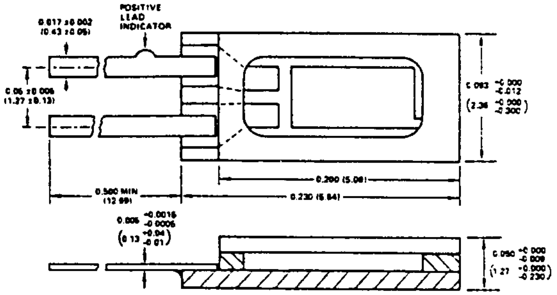


TEMPERATURE SCALE CONVERSION EQUATIONS

$$°C = \frac{5}{9}(°F - 32) \qquad K = °C + 273.15$$

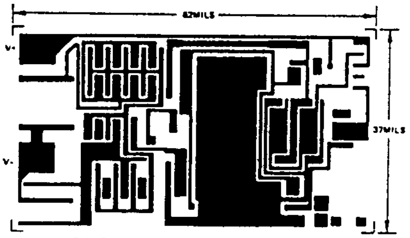
$$°F = \frac{9}{5}°C + 32 \qquad °R = °F + 459.7$$

The 590H has 60µ inches of gold plating on its Kovar leads and Kovar header. A resistance welder is used to seal the nickel cap to the header. The AD590 chip is eutectically mounted to the header and ultrasonically bonded to with 1 MIL aluminum wire. Kovar composition: 53% iron nominal; 29% ±1% nickel; 17% ±1% cobalt; 0.65% manganese max; 0.20% silicon max; 0.10% aluminum max; 0.10% magnesium max; 0.10% zirconium max; 0.10% titanium max; 0.06% carbon max.



FLAT-PACK PACKAGE: DESIGNATION "F"

The 590F is a ceramic package with gold plating on its Kovar leads, Kovar lid, and chip cavity. Solder of 80/20 Au/Sn composition is used for the 1.5 mil thick solder ring under the lid. The chip cavity has a nickel underlay between the metalization and the gold plating. The AD590 chip is eutectically mounted in the chip cavity at 410°C and ultrasonically bonded to with 1 mil aluminum wire. Note that the chip is in direct contact with the ceramic base, not the metal lid.



THE AD590 IS AVAILABLE IN LASER-TRIMMED CHIP FORM. CONSULT THE CHIP CATALOG FOR DETAILS.

Metalization Diagram

CIRCUIT DESCRIPTION[1]

The AD590 uses a fundamental property of the silicon transistors from which it is made to realize its temperature proportional characteristic: if two identical transistors are operated at a constant ratio of collector current densities, r, then the difference in their base-emitter voltages will be (kT/q)(ln r). Since both k, Boltzman's constant and q, the charge of an electron, are constant, the resulting voltage is directly proportional to absolute temperature (PTAT).

In the AD590, this PTAT voltage is converted to a PTAT current by low temperature coefficient thin film resistors. The total current of the device is then forced to be a multiple of this PTAT current. Referring to Figure 1, the schematic diagram of the AD590, Q8 and Q11 are the transistors that produce the PTAT voltage. R5 and R6 convert the voltage to current. Q10, whose collector current tracks the collector currents in Q9 and Q11, supplies all the bias and substrate leakage current for the rest of the circuit, forcing the total current to be PTAT. R5 and R6 are laser trimmed on the wafer to calibrate the device at +25°C.

Figure 2 shows the typical V–I characteristic of the circuit at +25°C and the temperature extremes.

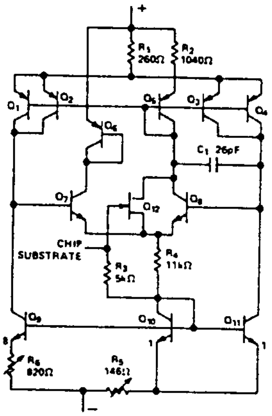


Figure 1. Schematic Diagram

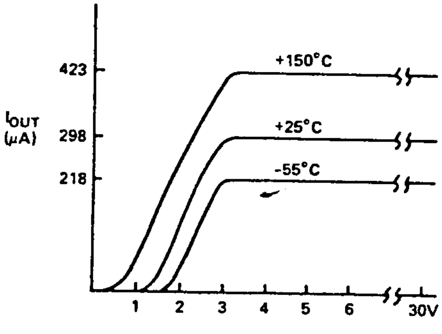


Figure 2. V–I Plot

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[1] For a more detailed circuit description see M.P. Timko, "A Two-Terminal IC Temperature Transducer," IEEE J. Solid State Circuits, Vol. SC-11, p. 784-788, Dec. 1976.

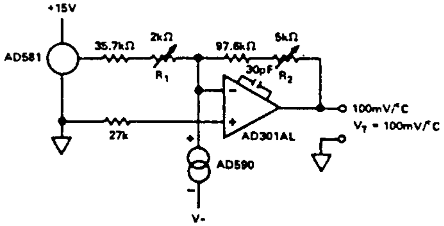

Figure 7A. Two Temperature Trim

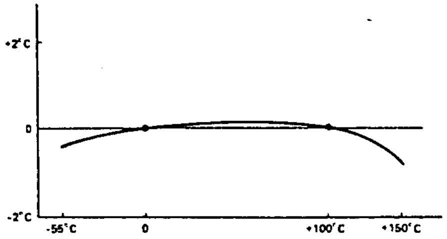

Figure 7B. Typical Two-Trim Accuracy

VOLTAGE AND THERMAL ENVIRONMENT EFFECTS

The power supply rejection specifications show the maximum expected change in output current versus input voltage changes. The insensitivity of the output to input voltage allows the use of unregulated supplies. It also means that hundreds of ohms of resistance (such as a CMOS multiplexer) can be tolerated in series with the device.

It is important to note that using a supply voltage other than 5V does not change the PTAT nature of the AD590. In other words, this change is equivalent to a calibration error and can be removed by the scale factor trim (see previous page).

The AD590 specifications are guaranteed for use in a low thermal resistance environment with 5V across the sensor. Large changes in the thermal resistance of the sensor's environment will change the amount of self-heating and result in changes in the output which are predictable but not necessarily desirable.

The thermal environment in which the AD590 is used determines two important characteristics: the effect of self heating and the response of the sensor with time.

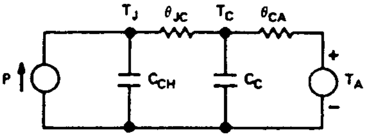

Figure 8. Thermal Circuit Model

Figure 8 is a model of the AD590 which demonstrates these characteristics. As an example, for the TO-52 package, θ_{JC} is the thermal resistance between the chip and the case, about 26°C/watt. θ_{CA} is the thermal resistance between the case and its surroundings and is determined by the characteristics of the thermal connection. Power source P represents the power dissipated on the chip. The rise of the junction temperature, T_J, above the ambient temperature T_A is:

$$T_J - T_A = P\,(\theta_{JC} + \theta_{CA}). \qquad \text{Eq. 1}$$

Table I gives the sum of θ_{JC} and θ_{CA} for several common thermal media for both the "H" and "F" packages. The heatsink used was a common clip-on. Using Equation 1, the temperature rise of an AD590 "H" package in a stirred bath at +25°C, when driven with a 5V supply, will be 0.06°C. However, for the same conditions in still air the temperature rise is 0.72°C. For a given supply voltage, the temperature rise varies with the current and is PTAT. Therefore, if an application circuit is trimmed with the sensor in the same thermal environment in which it will be used, the scale factor trim compensates for this effect over the entire temperature range.

MEDIUM	$\theta_{JC} + \theta_{CA}$ (°C/watt)		τ (sec) (Note 3)	
	H	F	H	F
Aluminum Block	30	10	0.6	0.1
Stirred Oil[1]	42	60	1.4	0.6
Moving Air[2]				
With Heat Sink	45	–	5.0	–
Without Heat Sink	115	190	13.5	10.0
Still Air				
With Heat Sink	191	–	108	–
Without Heat Sink	480	650	60	30

[1] Note: τ is dependent upon velocity of oil; average of several velocities listed above.

[2] Air velocity ≈ 9ft/sec.

[3] The time constant is defined as the time required to reach 63.2% of an instantaneous temperature change.

Table I. Thermal Resistances

The time response of the AD590 to a step change in temperature is determined by the thermal resistances and the thermal capacities of the chip, C_{CH}, and the case, C_C. C_{CH} is about 0.04 watt-sec/°C for the AD590. C_C varies with the measured medium since it includes anything that is in direct thermal contact with the case. In most cases, the single time constant exponential curve of Figure 9 is sufficient to describe the time response, T(t). Table I shows the effective time constant, τ, for several media.

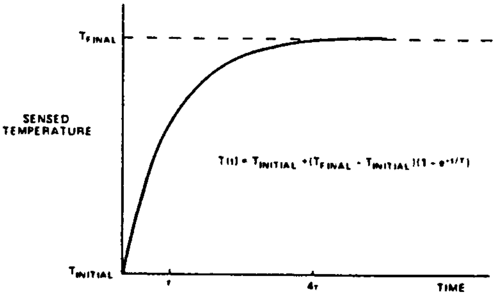

Figure 9. Time Response Curve