Current Consumption in NMOS COPS™ Microcontrollers

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Current consumption in the N-channel COPS microcontrollers is a function of manufacturing process variation and three operating condition parameters: temperature, voltage, and frequency. The aforementioned process variation swamps all other variations. Of the operating condition parameters, temperature is by far the most significant. This application brief is intended to provide the user with a guide to approximate the worst-case current consumption of the NMOS COPS microcontroller at a given set of operating conditions and to approximate the current variation with respect to temperature, voltage, and frequency.

Note that this is a guide only. Some approximations in the equations have been made. Only the current values found in the various device data sheets are guaranteed. Values derived by the techniques described here are neither guaranteed nor tested.

PROCESS VARIATION

If a user were to measure the current in two identical COPS microcontrollers under identical operating conditions (i.e., same temperature, voltage, and frequency), the results would probably be different. The reason for this difference is variation in the manufacturing process within its valid range. This variation can be quite substantial; a range of about 3 to 1 can be expected. This variation is essentially a device-to-device variation and basically not related to the operating conditions of the device. The three operating condition parameters (temperature, voltage, and frequency) affect current in the manner described below.

The values for current consumption in the various device data sheets are worst-case maximum values and assume that the processing parameters are at the end of the valid range which will produce maximum current consumption in the device.

THE EFFECT OF FREQUENCY

The frequency effect on current consumption is primarily a device design consideration. The higher the intended operating frequency, the higher the maximum current. However, once the device is designed in this process for a given maximum frequency, there is little variation with operating frequency. To be sure, there is some variation. As might be expected, current consumption is greater at higher frequencies. The variation is, however, slight—typically less than 5%.

THE EFFECT OF VOLTAGE

The operating voltage of the microcontroller has a slightly greater effect on current consumption than the operating current. Current consumption increases with increasing operating voltage. On examining the MOS device equations, one finds that the device current is proportional to the square of a voltage term:

$$I \; \alpha \; (V_{GS} - V_T)^2$$

where:

I = device current

V_{GS} = device gate to source voltage

V_T = device threshold voltage.

In the N-channel COPS devices, current is consumed primarily by the load devices. Most of these devices, though not all, are depletion mode devices with the gate and source tied together. Thus, V_{GS} is 0. Therefore, the primary mechanism for current consumption as related to voltage is variation in V_T. The depletion mode load devices in the COPS NMOS microcontrollers have geometries (length is much greater than width) which tend to minimize variations in threshold voltage. There are additional second order effects related to operating voltage, such as effective channel lengths shortening due to increased voltage, which affect current consumption. These effects, however, do not have a major impact on current consumption. Note also that the threshold voltage is affected by process variation. This is one of the areas where the process variation contributes to the device-to-device variation in current consumption. The user can typically expect to see a 5% to 10% variation in current due to operating voltage with the maximum current consumption occurring at maximum operating voltage.

THE EFFECT OF TEMPERATURE

Of the three operating parameters affecting current consumption in the NMOS COPS microcontrollers, temperature has by far the greatest impact. The relationship is given by the following simplified, empirical equation:

$$I(T) = I_O(T/T_O)^{-3/2}$$

where:

T_O = reference junction temperature in °K

T = device junction temperature in °K

I_O = device current at temperature T_O

$I(T)$ = device current at temperature T.

Although this equation is for a single transistor, it can be applied to the entire microcontroller since all the devices are made with the same process and will exhibit the same

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characteristics. It should also be noted that the temperatures involved are device junction temperatures. The junction temperature is essentially a function of two items:

$T_j = F(T_A, \theta_{jA})$

where:

T_j = junction temperature

T_A = ambient temperature

θ_{jA} = package thermal characteristic.

The preceding relationship indicates that the package for the device will affect current because the package affects junction temperature. This should not come as a surprise. One need only consider the differences between ceramic and plastic packages to find support for this claim.

For purposes of discussion, it will be assumed that junction temperature is given by the following:

$T_j = T_A + 25°K$

where T_j and T_A are as defined previously. Note that this is an approximation. It is not necessarily true for all packages, or any package. The relationship between junction temperature and ambient temperature is also not necessarily linear. However, the approximation is reasonable and provides a workable framework.

Substituting the junction temperature relationship into the current equation, the following equation results:

$$I(T_A) \cong I_O \left(\frac{T_A + 25}{T_{AO} + 25}\right)^{-3/2}$$

where:

T_{AO} = reference ambient temperature, °K

T_A = ambient temperature, °K

I_O = current at ambient temperature T_{AO}

$I(T_A)$ = current at ambient temperature T_A.

AN EXAMPLE

The COP320L has a specified maximum current of 10 mA. In this process, maximum current occurs at minimum temperature, which is −40°C in this case. It is desired to find the maximum current at 25°C. Therefore,

$T_{AO} = -40°C = 233°K$

$T_A = 25°C = 298°K$

$I_O = 10$ mA

$I(T_A)$ to be determined

$$I(T_A) \cong I_O \left(\frac{T_A + 25}{T_{AO} + 25}\right)^{-3/2}$$

$$\cong 10 \text{ mA } (323/258)$$

$$\cong 7.14 \text{ mA.}$$

Thus the maximum current for the COP320L at 25°C is approximately 7 mA.

CONCLUSION

A means is provided to the user to approximate the current variation of the NMOS COPS microcontroller over its valid operating range. A given device will consume its maximum current at maximum operating voltage, maximum operating frequency, and minimum operating ambient temperature. Conversely, minimum current will be consumed at minimum operating voltage, minimum operating frequency, and maximum operating ambient temperature.

The user should remember that this document is intended as a guide only. The values produced here are reasonable but they are approximations and are not guaranteed values. The user should also remember that the equations and methods discussed here do not involve process variation. The numbers calculated approximate the worst-case maximum current values at a given set of operating conditions. The user should be prepared to see a wide range of values over the course of volume production.

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