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THE PRUDENT ENGINEER MUST LOOK BEYOND THE FIRST PAGE OF THE DATA SHEET; THE FINE PRINT CAN KILL YOU.

How to read a semiconductor data sheet

SEMICONDUCTOR DATA SHEETS have changed a lot in the last few years, including growing from 10 pages to a hundred. The problem is that data sheets contain almost too much data, and there's not enough time for a busy engineer to dwell on all that information. The situation demands that the design engineer quickly evaluate the data-sheet information, and the following strategy can help the engineer reach the essentials in minimum time.

THE SHOW WINDOW

There are no standard semiconductor data sheets, but the first page of every data sheet contains attractive headlines intended to gain the designer's attention. Data sheets contain a ton of information, and the front page holds a fraction of it. Although the front-page information is attractive, you can't base a design decision on it without reading and understanding the rest of the data sheet. The front page comprises the headline, features section, applications section, circuit description, lead diagram, and packaging information. Sometimes, the headline contains all guaranteed minimum/maximum data, and sometimes the front page gives all typical values. The inconsistency exists because the product team works together from design to marketing, keeping the customer's needs in mind; the team puts information on the front page that will appeal to its target audience.

The features section tries to exhibit the unique attributes of the IC, such as rail-to-rail operation, flags, and shutdown modes. Obviously, IC applications require essential design features, and additional features rarely count, even if they are free. For example, an enable function contributes nothing to the design of a "continuously on" IC and may be a source of problems if you incorrectly terminate it. Carefully look over the features to see how you can use them in a novel manner; you may not need an enable function, but it can function as a disable during transient or failure conditions. You can use unique features in many ways that IC designers and applications engineers never imagined.

The description section expands on the features section and gives more information on salient points. The two sections combine to give designers the immediate information required to make a go/no-go decision. Never discard this rhetoric, because it often contains gem-like descriptions of unusual functions or exceptional performance that may come in handy on new designs. The description section often discusses special items that might be important to designers, such as unity-gain stability, performance near the power rails, and new function leads.

The front page sometimes includes an applications section. IC designers usually design devices for a specific application, and this section lists that application along with peripheral applications. The description section employs a paragraph format, whereas the features and applications sections tend to be bulleted; therefore, the description often embellishes the features and applications sections.

The lead diagram uses a circuit symbol (such as a triangle for an op amp) to show lead-to-circuit connections, and the package diagram shows how the leads are brought out of the package. This important diagram is necessary to connect the IC in a circuit. Beware: Lead names are often inconsistent throughout a data sheet. The front page may call a lead a "plus input" or identify it with a plus sign, but later text may call it a "noninverting input lead."

The next item to examine is the absolute-maximum ratings table. If the application exceeds these

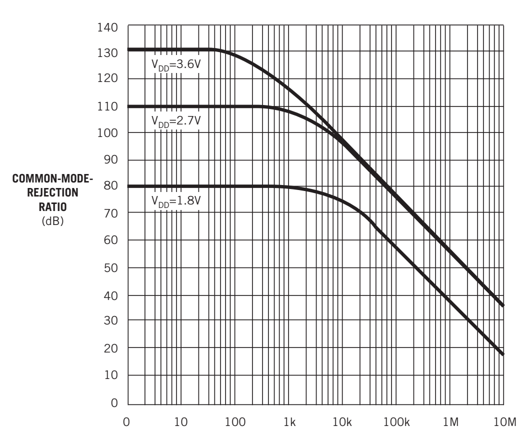

Figure 1 Typical curves illustrate the interactions between parameters of interest and external influences.

ratings, it voids the manufacturer's guarantee regardless of the duration or the conditions of the overstress. Manufacturers guard-band these ratings to obtain test tolerances, and some users try to push the envelope, taking advantage of the guard band by testing to establish the higher absolute-maximum rating. Never exceed the absolute-maximum ratings that the manufacturer recommends, regardless of the circumstances, because the manufacturer can change the guard band at any time. Most problems with absolute-maximum ratings occur during transient conditions, which extensive environmental and probable-use testing finds. Part of the circuit-design task of the device user is to eliminate the transient conditions or to minimize their effect using protective components.

The data sheet normally gives three absolute-maximum temperature ratings. Operating temperature is the maximum temperature range over which you can expect the IC to operate. Do not be confused between operating temperature and parameter specifications, because there is no relationship between them, and there is no guarantee that the IC will meet specifications over the operating-temperature range. Junction temperature is the maximum temperature that the IC's internal die can reach under any condition. If, for example, the maximum junction-temperature specification is 150°C and the operating-temperature range extends to 150°C, you cannot power up the IC at 150°C ambient, because any applied power increases the junction temperature beyond its rating. Storage temperature is the maximum temperature that the IC may reach under a power-off condition. Violating the storage-temperature limit voids the IC warranty.

Every data sheet includes an ESD (electrostatic-discharge) warning. Never ignore this warning, because ESD is always present and, like Murphy's Law, waiting to strike at the least opportune moment. Some users say that they do not worry about ESD because they use bipolar semiconductors. This belief is a fallacy, because 800V ESD can damage the base-emitter junctions of sensitive bipolar transistors, yet this voltage is low for static, and you cannot feel it. Always follow ESD-approved handling and installation procedures.

Carefully study the electrical characteristics in **tables 1** and **2**, because the design data comes from them. The table notes specify the test temperature and power-supply voltage. They include the comment, "unless otherwise noted," to ensure that individual test conditions supersede the general note. The test temperature is usually the temperature of the free air surrounding the IC, often 25°C, but power ICs often specify the test temperature as case temperature.

The body of the tables includes the parameter identification, test conditions, temperature (unless it's included in the test conditions), parameter data, and parameter units. Parameter identification includes the parameter symbol and name (that is, input offset voltage, V_{IO}, or offset voltage, V_{OS}). Life would be easier if the parameter names and symbols conformed to universal standards, but they don't, so users must translate symbols when scanning multiple data sheets from multiple manufacturers. Furthermore, parameter names or symbols are sometimes inconsistent between pages in a data sheet. Rather than make assumptions, users must contact the manufacturer's applications department to get confirmation or a clear answer.

Carefully read the test conditions; the parameter values are valid only when the test conditions prevail. The test-conditions column specifies the test ambient temperature when the data sheet does not use a separate temperature column. It also specifies power-supply voltages and some of the test parameters, such as source resistance, load resistance, test frequency, common-mode voltage, open-loop gain, input signal, and any other important defining test parameters.

These test conditions sometimes lead to apparent conflicts with the front page. The front page may list an ADC performance as 16 bits at 1M sample/sec, but the guaranteed conversion rate at the test condition yields only 14 bits of guaranteed performance. Here, the front page advertises maximum performance for customers that can use typical data, and the table gives guaranteed performance for the conservative customers. After weeding out nonperforming ICs to establish the initial selection based on front-page data, designers must rely on the data in the electrical-characteristics table. Test conditions usually make the difference between front-page and electrical-charac-

TABLE 1–PARAMETERS FOR THE OFFSET VOLTAGE OF A SIGNAL OP AMP

Parameter	Test conditions		T_A*	MIN	TYP	MAX	Unit
V_{IO} (input offset voltage)	V_O=V_{DD}/2, R_L=2 kΩ, R_S=50Ω	TLV278x	25°C		250	3000	μV
			Full range			4500	
		TLV278xA	25°C		250	2000	
			Full range			3000	
∝V_{IO} (temperature coefficient of input offset voltage)					8		μV/°C
CMRR (common-mode rejection ratio)	V_{IC}=0 to V_{DD}, R_S=50Ω	V_{DD}=1.8V	25°C	50	76		dB
			Full range	50			
		V_{DD}=2.7V/3.6V	25°C	55	80		
			Full range	50			
	V_{IC}=1.2V to V_{DD}, R_S=50Ω	V_{DD}=2.7V/3.6V	25°C	70	100		
			Full range	70			

Notes: Electrical characteristics at specified free-air temperature, V_{DD}=1.8V, 2.7V (unless otherwise noted).
*Full range is 0 to 70°C for the C suffix and −40 to +125°C for the I suffix. If unspecified, full range is −40 to +125°C.

TABLE 2–PARAMETERS FOR THE OFFSET VOLTAGE OF A POWER OP AMP

Parameter	Condition	OPA569 MIN	OPA569 TYP	OPA569 MAX	Units
Offset voltage					
Input offset voltage (V_{OS})	I_O=0V, V_S=5V		±0.5	±2	mV
versus temperature (dV_{OS}/dT)	T_A=−40 to +85°C		±1.3		μV/°C
versus power supply (PSRR)	V_S=2.7V to 5.5V, V_{CM}=(V−)+0.55V		12	60	μV/V

Electrical characteristics: V_S=2.7 to 5.5V. Boldface limits apply over the specified temperature range, T_A=−40 to +85°C. At T_{CASE}=25°C, RL=1 kΩ, and connect to V_S/2, unless otherwise noted.
Note: PSRR=power-supply rejection ratio.

teristics data, so carefully peruse the test conditions.

The temperature column specifies the test temperature when the test-conditions column omits this value. This column often has values of 25°C, full range, or a numerical temperature range. Full range means different temperature ranges exist for different grades of ICs; thus, designers must read and understand any notes pertaining to "full range." For example, full range can be 0 to 70°C for the lowest grade of an IC family (often C grade), or it can be −40 to +125°C for a premium grade (often I grade). Regardless of any other temperature rating or specification, the parameter values in the table are valid only for the specified temperature or temperature range. Sometimes, the operating-temperature range and test-condition/temperature-column specifications are identical; when they differ, the test-condition/temperature column values prevail.

The next column subdivides into three columns—MIN for minimum, TYP for typical, and MAX for maximum—that contain the available parameter values. After initial testing on the first several groups of ICs, the manufacturer applies statistics to the data to obtain the mean value for each parameter. The statistics yield the variance, sigma; six times sigma represents the maximum and minimum values that the parameters assume during manufacturing. These six sigma points become the minimum and maximum values for that parameter, and you often use the mean as the typical specification.

The V_{IO} parameter for the TLV278X signal op amp has typical and maximum values but no minimum value. Ideally, the value of V_{IO} approaches zero; this situation may happen someday, so the data sheet leaves this value blank. The V_{IOMAX} specification is 3000 μV at T_A=25°C and 4500 μV over the full temperature range. The polarity of V_{IO} is unspecified, and designers have to read outside material to find out that because either input lead can dominate V_{IO}, the range of V_{IO} is −3000 μV≤V_{IO}≤3000 μV (**Reference 1**).

Parameter specifications are functions of the test circuit, test conditions, and the IC. Most data sheets do not contain test-circuit diagrams, but they are available for most measurements, so designers can gain an understanding of test circuits to understand the specifications. The CMRR (common-mode rejection ratio) has minimum and typical values and no maximum values. Infinite CMRR would be a designer's dream, so data sheets give no maximum parameter value.

Typical values can get novice or naive designers in trouble because they show desirable parameter values that the IC cannot dependably deliver. There is a tendency to lust over typical values even when the data sheet gives minimum/maximum values, and this path can lead straight to an unreliable design. Engineers who prefer using minimum/maximum values might be tempted to use a typical value when minimum/maximum values are unavailable, but the absence of minimum/maximum values does not make typical values design parameters. Sometimes typical values are the mean or average value you obtain from several sample runs of an IC, but often, typical values have little relationship to today's ICs. An IC may go through several mask sets, process changes, or both, throughout its life, and the original typical values lose their meaning after all these changes. (In more than 20 years, I have never seen the typical values change on the LM324 data sheet after the IC process/mask was changed!)

Sometimes, designers can obtain only typical values for a parameter; this situation is especially true when dealing with high-speed components, because the test cost can exceed the production cost. When the question arises about whether you should use typical values because they are the only data you have, the answer is no, unless you have an understanding with the manufacturer. Designers should first try to obtain data and specifications from the manufacturer, which often can record and log data. This approach can be cost-prohibitive, so the next step is to arrange for the manufacturer to supply GNT (guaranteed-but-not-tested) or GBD (guaranteed-by-design) specifications. GNT means that the manufacturer pulls quality-control samples and tests the lot for the parameter of interest. If the parameter test fails, the manufacturer doesn't ship parts from that lot. GBD involves parameters physically tied to a tested parameter; if the tested parameter passes, the GBD parameter passes. When a special customer-manufacturer relationship exists, the manufacturer can negotiate an agreement that enables the use of typical parameters. If you can't obtain manufacturer data, you can obtain several lots of ICs with different date codes, perform parameter measurements, and do a statistical analysis to obtain minimum/maximum values. This method is less dependable than the manufacturer's guarantee, but it is better than relying on nonguaranteed typical data.

FOLLOW THOSE CURVES

Curves are valuable tools for determining how one parameter interacts with another parameter, temperature, frequency, or power-supply variation. **Figure 1** shows the CMRR-versus-frequency curve for the TLV278X op amp.

The curves show the dc CMRR as 80 dB at V_{DD}=1.8V, 110 dB at V_{DD}=2.7V, and 130 dB at V_{DD}=3.6V. The electrical-characteristics table says that the typical dc CMRR is 76 dB at V_{DD}=1.8V and 80 or 100 dB at V_{DD}=2.7/3.6V. This data raises a question of why the CMRRs are unequal for equal supply voltages. The reason is that the input common-mode-voltage specification covers a voltage range in **Table 1** (see the test conditions).

This exercise illustrates the value of understanding the test conditions. The TLV278X is a consistent data sheet; load capacitance and resistance are constant at 10 pF and 2 kΩ. Some data sheets are less consistent, with parameters that look good until you read the fine print. For example, I once read a Bode plot and predicted an overshoot of 40%. The pulse curves had virtually no overshoot. The difference was that the Bode-plot circuit had a 1000-pF load, and the overshoot circuit had a 10-pF load.

The applications-information section often includes parameter-measurement information, along with unusual measurement circuits. The application section discusses topics including load-driving capability, pc-board-layout suggestions, special stabilization techniques, Spice models, special-function descriptions, safe-operating-area curves, heat-sinking graphs, and applications circuits. An applications engineer who wants to show an IC in its best light generates this information, so pay special attention to pc-board-layout suggestions to obtain the best ac results. Most manufacturers include layout artwork in this section, or they give designers layout artwork in an attempt to maximize their IC's performance in the circuit.

Circuit descriptions of the IC or of applications of the IC in this section are entertaining and informative. The applications engineers build and test each circuit, but the fact that they do so is no guarantee that the circuits will work when *you* build them, so you should use the applications circuits as starting points in your design. Write the design equations, build the circuit, and test to validate the performance. Remember, the strength of a semiconductor-applications engineer is designing circuits that are functional and that catch the reader's eye. It is not designing reliable circuits for high-volume production, although they often have this capability, too. Designers get the most design information from the parameter section, but the applications section supplies plenty of important information, so thoroughly read it. Often, topics that seem of little interest at first glance yield good information after some study. If you don't understand anything in the applications section, don't hesitate to contact the manufacturer's applications engineers for help, but read the data sheet first; many applications questions are answered by the applications engineer reading the data sheet to the design engineer.

The applications section includes package and lead dimensions. Most IC packages have standard external dimensions, but check to ensure both compatibility and that the package-type material contains adequate dimensional information. Always check special packages for dimensions, unique lead functions, heat-sink requirements, and other potential problem areas.

All data sheets contain a number of disclaimers, and designers should read and understand them. The disclaimers cover use in critical applications, the right to change the product without notification, intellectual-property rights, and the limit of application-circuit responsibility. But read the data sheet; this list is incomplete. Fully understand which disclaimers apply to the product, because disclaimers vary among products and manufacturers.

MAKE THEM YOUR ALLIES

Data sheets contain adequate data to complete most circuit designs. Design with guaranteed minimum/maximum data unless this data is unavailable. When it is unavailable, do not jump to typical data as a substitute; rather, contact the manufacturer for GNT specifications, GBD specifications, and parameter data, or generate reliable statistical data. Data sheets contain a wealth of information, and the time you spend reading them will pay off in better and faster designs. The front page may be attractive, but the food is inside, so have a good meal.□

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REFERENCE

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