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TUTORIAL 4294

Differential Gain and Phase—Why Measure It, if You Cannot See It?

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Abstract: Differential gain and phase (DG and DP) are common video specifications. What are they? Why are they used if they cannot be seen? This application note answers these questions, and explains how these specifications are applied to other nonvideo amplifiers, ADCs, and DACs.

A similar article was published February 18, 2011 in *Planet Analog*.

Technology Update

In the four years since the article was written, the video world has undergone major changes. High definition (HD) in many forms has replaced encoded systems like NTSC and PAL. The information is still relevant because of the existing installed base and of new industrial and security systems where a single coax connection is convenient.

Differential phase (DP) only applies to encoded systems with a reference burst. So with most HD, there is no DP. However, differential gain (DG) was first a black-and-white TV test. It is also a good way to explore the linearity of analog amplifiers for applications other than television. **Figure 1** is a low-frequency staircase with a high frequency superimposed. Placing a small high-frequency sine wave (about 2/3 to 3/4 of the system bandwidth) on top of a larger lower-frequency sine wave will have the same effect. If the pair of signals is low level and centered between the power rails (the sweet spot), the output will have the best linearity (**Figure 2**). As the low-frequency signal increases in amplitude, the high-frequency signal will distort first. The second and even harmonics will increase if the distortion is asymmetrical top-to-bottom. If the signal distorts evenly top and bottom, the third and odd harmonics will increase.

Introduction

Many say that video differential gain and phase (DG and DP) are not visible to the human eye. So why would anyone want to measure something that is invisible? How are DG and DP applied to amplifiers, analog-to-digital converters (ADCs), and digital-to-analog converters (DACs)? This application note will explain how one can actually "see" (measure) DG and DP and why the specifications are important.

How Can One See DG and DP?

A DG or DP video error means that a person's flesh tone will change as he or she moves from a brightly lit area to a dimly lit area. The gain change would alter the saturation or how vivid the color is, much like the chroma control on a TV. The phase will change the hue of the color (toward green or purple) like the tint control of a NTSC (North America and Japan) TV set. So while DG and DP do indeed exist, they are said to be "invisible" because the magnitude of change is usually small. Moreover, the fluctuating scene brightness masks the errors.

Why Are DG and DP Specifications Needed?

Think of how a TV program is created. Multiple camera signals are switched and sent through special-effects equipment, then recorded, played back, and edited on the way to becoming a program. The program can be distributed over long distances by microwave, fiber optics, or satellite to eventually be broadcast over the air. A cable or satellite system then brings the program into homes so viewers can enjoy it. In this process, the video may pass through hundreds of amplifiers. Each amplifier contributes a small amount of DG and DP. To be sure that the integrity of the video signal is preserved, engineers designed a very sensitive test signal. For example, a MAX4380 amplifier is specified with a low typical DG of 0.02% and DP of 0.08 degrees.

All amplifiers have some amount of nonlinear amplitude response. Negative feedback is utilized to reduce this nonlinearity. DG and DP are really specialized linearity measurements that account for frequency response. NTSC (US) and PAL (UK, Europe, and China) TV systems send the color information on a subcarrier (3.58MHz for NTSC, 4.43MHz for PAL). DG is defined as the change in amplitude of the high-frequency subcarrier when there is change in low-frequency video level or brightness. Figure 1 shows an NTSC video waveform. The 3.58MHz subcarrier is superimposed on a lower frequency luminance signal with five brightness steps. The subcarrier is drawn as single large sine waves for clarity. In fact, there are more than 200 subcarrier cycles across one horizontal line.

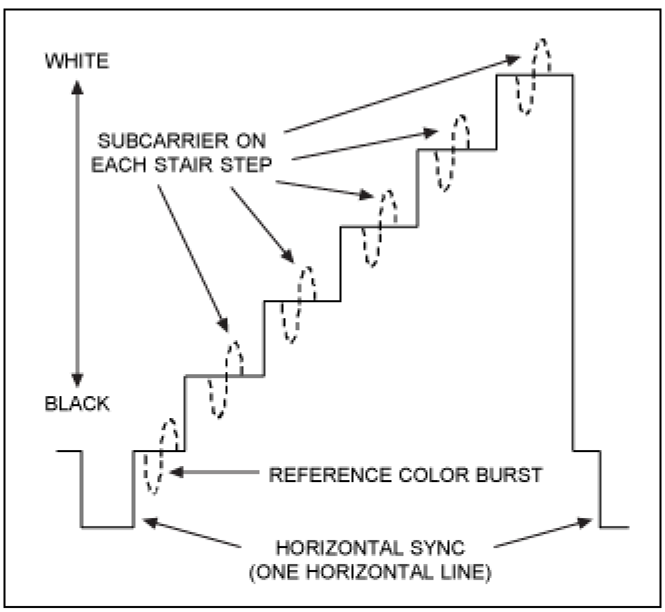

Figure 1. Video DG and DP.

DP is defined as the change in phase of the high-frequency subcarrier when the lower frequency video level or brightness changes in NTSC and PAL. The hue or tint of the color displayed is controlled by the phase relationship between the reference burst located in the black region of the video and the subcarrier present in the active video picture time. If the proper color is to be displayed, the phase must be accurately controlled.

Amplifiers, ADCs, and DACs have a "sweet spot" where they are most linear and meet the highest specifications or standards. This sweet spot is usually located midway between the two power rails (Figure 2), although the IC designer could place it at another point if necessary. Here the amplifier is operating with the best control over feedback and is naturally most linear. That means that, as a signal approaches the power-supply rails, the linearity is reduced. Superimposing a high-frequency sine wave on a low-frequency signal allows all of the amplifier's operating range to be explored. For example, if the application needs a 10MHz signal, an amplifier like the MAX4389 can be used by applying a 7MHz sine wave and then changing the DC bias. The sine-wave signal biased to midrange DC will have the best response. As the DC is changed to move the sine wave toward either power-supply rail, the sine-wave amplitude will change. Usually the high-frequency response is reduced as the power rail is approached and the transistor operating current is reduced. At the extreme condition the amplifier simply runs out of current, stops operating, and clipping occurs. ADCs and DACs can be checked in a similar manner.

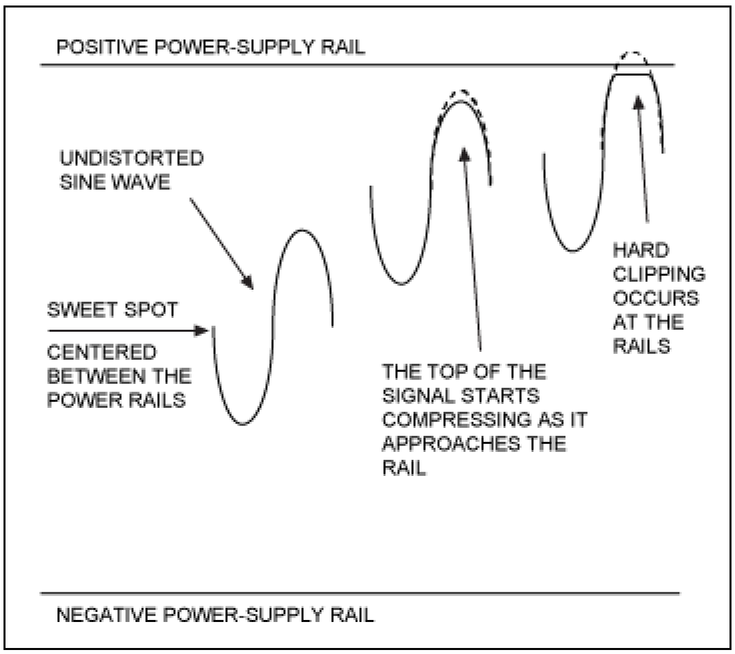

Figure 2 Amplifier DG and DP near the power rails.

As an IC becomes more complex and is more than just a single amplifier, more DG and DP error is expected. The MAX7428 video filter and buffer is specified at typical DG 0.2% and DP of 0.2 degrees. The video path is significantly more complicated as the video passes multiplex switches, a 6-pole Sallen-Key filter, and video buffer. That Sallen-Key filter is actually three or more amplifier stages.

Conclusion

So return to the original question: why measure something that cannot be seen? The DG and DP tests were designed to detect very small errors before that error could bother a human. This ensures good video quality when the video passes through hundreds of amplifiers in succession. For amplifiers, ADCs, and DACs, the performance can be verified both at the sweet spot and near the power rails. Again this process detects very small errors, thus ensuring signal integrity with multiple stages.

Maxim's complete list of op amps is available on the website.

Related Parts		
MAX1135	16-Bit ADCs, 150ksps, 3.3V Single Supply	Free Samples
MAX11504	Four-Channel, Standard-Definition Video Filters	Free Samples
MAX11506	Low-Cost, 6-Channel SD Plus HD/SD Selectable Video Filters and Buffers	Free Samples
MAX1190	Dual 10-Bit, 120Msps, 3.3V, Low-Power ADC with Internal Reference and Parallel Outputs	Free Samples
MAX1193	Ultra-Low-Power, 45Msps, Dual 8-Bit ADC	Free Samples
MAX1196	Dual 8-Bit, 40Msps, 3V, Low-Power ADC with Internal Reference and Multiplexed Parallel Outputs	Free Samples
MAX1198	Dual, 8-Bit, 100Msps, 3.3V, Low-Power ADC with Internal Reference and Parallel Outputs	Free Samples
MAX12559	Dual, 96Msps, 14-Bit, IF/Baseband ADC	Free Samples
MAX1301	8- and 4-Channel, ±3 x V_{REF} Multirange Inputs, Serial 16-Bit ADCs	Free Samples
MAX1338	14-Bit, 4-Channel, Software-Programmable, Multiranging, Simultaneous-Sampling ADC	
MAX1446	10-Bit, 60Msps, 3.0V, Low-Power ADC with Internal Reference	Free Samples
MAX1449	10-Bit, 105Msps, Single +3.3V, Low-Power ADC with Internal Reference	Free Samples
MAX153	1Msps, µP Compatible, 8-Bit ADC with 1µA Power Down	Free Samples
MAX188	Low-Power, 8-Channel, Serial 12-Bit ADCs	Free Samples
MAX4124	Single/Dual/Quad, Wide-Bandwidth, Low-Power, Single-Supply Rail-to-Rail I/O Op Amps	Free Samples
MAX4233	High-Output-Drive, 10MHz, 10V/µs, Rail-to-Rail I/O Op Amps with Shutdown in SC70	Free Samples
MAX4239	Ultra-Low Offset/Drift, Low-Noise, Precision SOT23 Amplifiers	Free Samples
MAX4380	Ultra-Small, Low-Cost, 210MHz, Single-Supply Op Amps with Rail-to-Rail Outputs and Disable	Free Samples
MAX4389	Ultra-Small, Low-Cost, 85MHz Op Amps with Rail-to-Rail Outputs and Disable	Free Samples
MAX4488	SOT23, Low-Noise, Low-Distortion, Wide-Band, Rail-to-Rail Op Amps	Free Samples

MAX4489	SOT23, Low-Noise, Low-Distortion, Wide-Band, Rail-to-Rail Op Amps	Free Samples
MAX5115	Nonvolatile, Quad, 8-Bit DACs with 2-Wire Serial Interface	Free Samples
MAX5183	Dual, 10-Bit, 40MHz, Current/Voltage Simultaneous-Output DACs	Free Samples
MAX5195	14-Bit, 260Msps High-Dynamic Performance DAC	
MAX5206	Low-Cost, Voltage-Output, 16-Bit DACs in µMAX	Free Samples
MAX5385	Low-Cost, Low-Power, 8-Bit DACs with 3-Wire Serial Interface in SOT23	
MAX5524	Dual, Ultra-Low-Power, 10-Bit, Voltage-Output DACs	Free Samples
MAX555	300Msps, 12-Bit DAC with Complementary Voltage Outputs	
MAX5550	Dual, 10-Bit, Programmable, 30mA High-Output-Current DAC	Free Samples
MAX5591	Buffered, Fast-Settling, Octal, 12/10/8-Bit, Voltage-Output DACs	Free Samples
MAX5774	32-Channel, 14-Bit, Voltage-Output DACs with Serial Interface	Free Samples
MAX5858A	Dual, 10-Bit, 300Msps, DAC with 4x/2x/1x Interpolation Filters and PLL	Free Samples
MAX7428	Standard Definition Video Reconstruction Filters and Buffers	Free Samples
MAX9516	1.8V, Ultra-Low-Power, DirectDrive Video Filter Amplifier with Load Detect	Free Samples
MAX9524	Standard-Definition Video Filter Amplifiers with Dual SPST Switches	Free Samples
MAX9910	200kHz, 4µA, Rail-to-Rail I/O Op Amps with Shutdown	Free Samples
MAX9914	1MHz, 20µA, Rail-to-Rail I/O Op Amps with Shutdown	Free Samples

More Information
For Technical Support: http://www.maximintegrated.com/support
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Application Note 4294: http://www.maximintegrated.com/an4294
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