Measuring and Improving Differential Gain and Differential Phase for Video

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Differential gain (DG) and differential phase (DP) are two specifications that designers of composite video systems use everyday. We will define them here just to be sure we are all speaking the same language, and to ensure understanding of the rationale of the test technique used by National.

Composite video encodes brightness (luminance), timing (sync), and color (chrominance) into one channel. Luminance is the voltage offset from a reference, or "black", level. Sync appears at a level defined as "blacker than black." Chrominance is encoded as a high-frequency (with respect to the luminance signal) subcarrier. The average value (midpoint) of the chrominance is the luminance. The color has two "dimensions": amplitude which determines the saturation, and phase relative to a reference chrominance burst which encodes the hue. For example, pink has the same relative phase as red, but of a lower amplitude, hence a less saturated red. Red in NTSC is shifted 103.7˚ from the reference, green 241.3˚.

DG and DP are measured at one of two chrominance subcarrier frequencies. NTSC (National Television Systems Committee, 1953) uses a 3.579545MHz color subcarrier. Phase Alternation Line (PAL) alternates the phase of the reference burst with every scan line. The PAL subcarrier frequency is 4.433619MHz.

Differential phase is a change in chrominance (high-frequency) phase with luminance level. This manifests itself in the picture as a color hue shift as the illumination changes. A blue parrot indoors does not become a purple parrot in the sun. Differential gain is a change in chrominance gain with luminance level. The saturation changes in the viewed scene as the brightness varies. A red shirt at noon must not turn pink at night. Both are distortions which, if sufficiently large, can be perceived by the eye.

Another way to think of DG error in a signal channel or amplifier is a magnitude variation of a high-frequency sinusoid (the subcarrier) as its offset changes. This offset can be, at its simplest and crudest, a DC offset. It can also take the form of a low-frequency sinusoid or ramp. Similarly, an alternative way to view DP is as a change in the carrier phase shift of the channel over the range of offset simulating the luminance (see *Figure 1*).

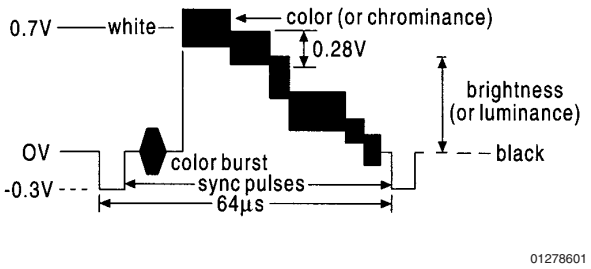


FIGURE 1.

The traditional way of measuring the DG and DP of broadcast video equipment such as a switcher or a distribution amplifier, DA, is with a vectorscope. A distribution amp can have several integrated or discrete amplifiers between the input and output. Vectorscopes can measure such high-level systems to <1% DG and <1˚DP. Newer video test equipment based on digital technology, such as the Tektronix ©VM700, can make measurements to <0.03% and <0.03˚. This resolution results after the DG and DP errors of the video test signal generator have been calibrated out. This equipment is adequate to measure a complete video system, but cannot measure an individual operational amplifier to the required resolution.

Video designers usually take a worst-case approach when selecting a video op-amp. Consider, for example, the design of a DA with five amplifiers between the input and output. The desired overall system specification for this DA board is to be 0.05% DG and 0.05˚ DP. One then assumes each of the five op-amps will contribute "+0.01%" and "+0.01˚" of DG and DP, respectively. These errors will then add "in phase" for the total of "+0.05." There is not usually a sign associated with DG and DP, rather, the absolute value is used. The VM700 measures signed DG and DP for each step in a modulated staircase. The overall DG and DP, however, are displayed as an unsigned peak-to-peak magnitude. Modern video test equipment can measure the final DA but cannot

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measure the individual op-amps with the required resolution. Imagine, as well, the design of a system with better than 0.05 numbers. If it were possible to select one op-amp with +0.01% DG and another with –0.01%, the two would cancel to zero. Some state-of-the-art video test equipment is built this way.

Another concern, especially with advanced video test equipment, is squeezing the most out of an op-amp.

Refer to *Figure 1*, a positive video waveform. The video information is at voltages above 0V (positive video); the sync information is below 0V (negative sync). Video equipment must conform to a standard such as this at the input and output. What happens to the signal in between these external ports is only the designer's business. She may choose to invert the video (negative video, or positive sync) for gamma correction with an inverting summing circuit. Another compelling reason to work with inverted video is that a particular amplifier may have better DG, DP or both, with negative video. The "polarity" of DG and DP may change in a predictable way between negative and positive video. This feature (not a bug) may then be exploited to improve the system DG and DP specifications. It is not easy, using current industry-standard test equipment, to measure negative video DG and DP.

How We Do It

Comlinear uses an HP4195 network analyzer to make DG, DP measurements of its devices and customer circuits. There are many good reasons to choose this particular machine. The network analyzer has the gain and phase measuring capability to resolve significantly less than the 0.01% and 0.01˚ target specifications in the device under test, DUT. This particular analyzer has a built-in DC source which can be used as an independent sweep variable; single-frequency, CW, gain and phase can be measured and displayed parametrically on the DC source voltage. This allows the behavior of the amplifier over the entire luminance range, both positive and negative video, to be observed and characterized in detail. A qualitative, as well as quantitative, measurement of DG and DP can be made.

Trends in amplifiers can easily be seen. This is not possible with a box which only delivers numbers. Since network analyzers measure gain in V/V or dB, the trace mathematics of the HP4195 enable conversion to percentages. Finally the internal programming capability of this analyzer yields a self-contained DG and DP measurement system, which does not require an external computer and interface hardware/software yet still can be used for other purposes.

The machine needs a few ancillary items to make this specialized measurement. The CLC400 with ±6V supplies boosts the HP4195's DC sourcing ability. The DC source has limited drive current. The measurement of a unity gain buffer requires twice the input signal level, relative to a DUT with a gain of two, in order to maintain the correct output amplitudes. Operating the CLC400 with ±6V supplies increases the maximum output voltage of the device ±3.5V. The low-pass filter, with the CLC400, guarantees a 50W output impedance over frequency and DC level from the DC source into the power combiner. The power splitter sums the DC swept source (luminance) and AC oscillator (chrominance) passively, so no DG or DP is introduced into the input test signal. The R/T test set is needed for a controlled impedance throughout the test system. Comlinear uses a 50Ω test set for a 50Ω environment. A video designer would most likely have a 75Ω R/T test set at his disposal. In this case the 50Ω resistor on the output of the CLC400 would be 75Ω, the power combiner and filter would be 75Ω, etc.

The DUT, in a 50Ω system, would have a series 100Ω resistor between the DUT output and the 50Ω, 14dB attenuator. Thus the total driven load is the proper 150Ω for a 75Ω environment. With a 75Ω test set, a series resistor of 75Ω and a 14dB 75Ω pad would be used instead. Multiple video loads can be simulated by adding additional 150Ω resistors between the DUT output pin and earth. The AC test signal and the T2 analyzer input are capacitively coupled to isolate the DC from the source oscillator and from the analyzer receiver. The 14dB attenuator ensures that the test signal to be measured is of sufficiently low amplitude so as not to cause overload and distortions in the analyzer front end.

The software is straightforward. Previously, in Application Note OA-08 [Comlinear 1993-1994 data book, pages 11-27], we did a through calibration and subtracted this from the subsequent DUT measurement. This proved unnecessary once the lowpass filter, described above, was added. It is the change in gain and phase being measured here. The absolute gain or phase at any point on the DC sweep is irrelevant. The measurement to be made is S21. The straight amplitude-ratio measurement format is required here, not decibels. Averaging dB and converting to percent is problematic. The mathematics is easy to understand and program if non-dB measurements are made. The AC source is set to CW mode, the frequency to that of the desired color subcarrier for the system requirements. The amplitudes of the DC and AC sources are set.

Once the instrument has been set up, the measurement can begin. A sweep is triggered over the DC source sweep range. It is not necessary to have a large number of measurement points over the sweep. We measure a total of twenty-one points for clarity in the plotted data— 10 negative video, 10 positive video, and one reference black level. For the required resolution a number of measurements are averaged. We have found an average of 30 sweeps to be a good compromise between measurement time and resolution for most op-amps. Some, like the CLC400 and CLC410 with DG, DP ≤0.01, require an average of 50 measurements. There comes a point where further averaging does not enhance resolution.

After the raw data are collected, they are scaled and displayed. The gain data are converted to percentages. The percent gain and the phase data are scaled to fit on the screen. The trace mathematics built into the programming language find the maximum deviation, or peak-to-peak change in gain and phase, over the luminance sweep. Minimum and maximum DG and DP are found along the trace, and can be displayed as does the VM700. The final DG and DP numbers are displayed in addition to the sweep graph. A vectorscope also gives DG and DP as peak-to-peak magnitude. This is in accordance with NTSC standards.

There is one small problem with the programming language in this machine. Oscillator and DC source levels must be hard-coded and cannot be stored as variables for easy experimentation with different circuit gains and attenuations. This isn't too inconvenient, as most op-amps will be tested at a gain of two. The exact hardware chosen will have differing insertion losses which must be taken into account. The AC coupling may necessitate changing the oscillator level slightly between NTSC and PAL subcarrier frequencies. In current practice, engineers use the PAL 4.43MHz frequency,

How We Do It (Continued)

as it is considered to be the more demanding test condition. Also, a piece of equipment is often sold to countries with different broadcast standards. If a product meets the more stringent specification, one size fits all. Often a current feedback amplifier with 200MHz bandwidth at a gain of two displays little difference in DG and DP between the NTSC and PAL frequencies.

The practical upshot of this is that one must determine the appropriate oscillator amplitude and DC sweep range of each individual hardware assemblage empirically, with an oscilloscope. NTSC levels can be found as follows:

- Set the oscillator frequency to 3.58MHz
- To find the necessary DC sweep range, the AC source oscillator amplitude is first manually set to 1mV, as zero is not allowed by the HP4195 software
- Adjust the DC level from the front panel to yield 0.714V at the equivalent 75Ω load, or 1.424V the DUT output
- When the DC sweep range numbers have been found, these are then entered into the program. It is the programmed start- and stop-sweep voltages which are displayed on the HP4195 screen.

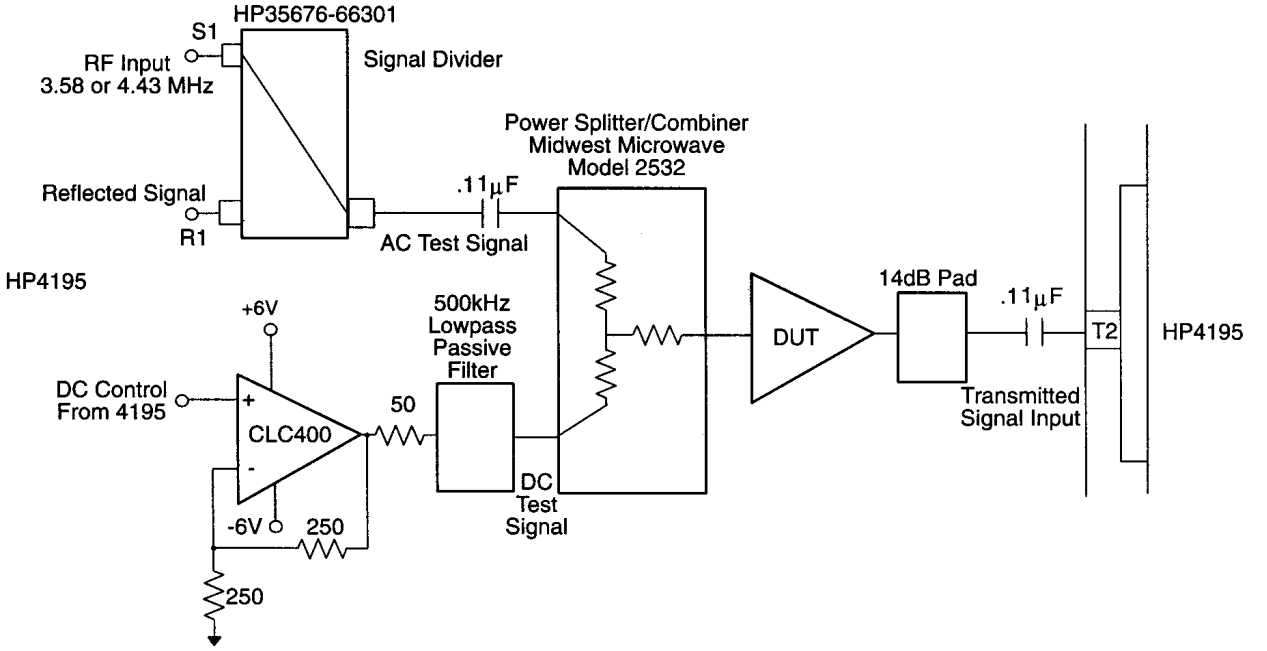


FIGURE 2. R/T Test Set

For example, one of our test setups results in 0.95V at the maximum luminance level. When the HP4195 DC source is set to 0.95V, a DUT at a gain of two has an output of 1.424V. To set the AC oscillator, begin by manually resetting the DC source to 0V. From the front panel, adjust the oscillator amplitude to yield 286mV$_{PP}$ at the equivalent 75Ω load, or 572mV$_{PP}$ at the DUT output. Note the oscillator setting and edit this into the test program (see *Figure 2*).

Look Carefully at How DG, DP are Specified In Datasheets

It is much easier to make measurements than it is to know exactly what you are measuring. — J.W.N. Sullivan, physicist, 1928

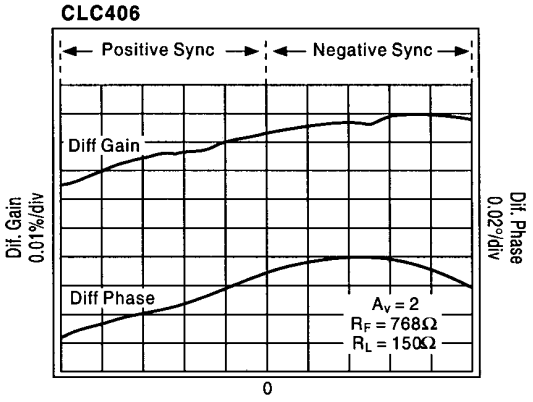
Figure 3 shows the measurement results of this test system. A CLC406 is shown. DG and DP are measured for both positive and negative sync (negative and positive video, respectively). The marked points show the specified DG and DP, (peak-to-peak) that is quoted in Comlinear's data sheet. Notice that we would get better numbers if we just took the delta between the endpoints of the sweep range, essentially a DC test at only two luminance levels. This is neither what the video standards delineate, or what vectorscopes or the VM700 report. Another interpretation of these standards implies an RMS value of the error. Neither Comlinear or Tektronix do this.

The VM700 display shows the DP/DG as the largest peak-to-peak delta over the luminance range. Simply giving the endpoint delta between black level and the white level can be misleading. DG and DP do not behave linearly with luminance. The VM700 gives signed DG, DP numbers to each step of the modulated staircase, similar to the HP4195 program. Both pieces of equipment can be used for device characterization and screening for best system performance. The final DG, DP number is the worst-case, peak-to-peak magnitude measured over the entire, continuous, luminance range.

Some manufacturers measure gain and phase at 0V and 0.714V and then tell you the difference. With elan, they call this DG and DP in the data sheet discussion. This would only make sense if the amplifier's DG and DP errors were perfectly linear with respect to luminance. Comlinear has never

Look Carefully at How DG, DP are Specified In Datasheets (Continued)

measured such a device from any manufacturer. When represented graphically, as in *Figure 3*, DG and DP are not represented by a straight line, but appear more like a quadratic or even cubic function.

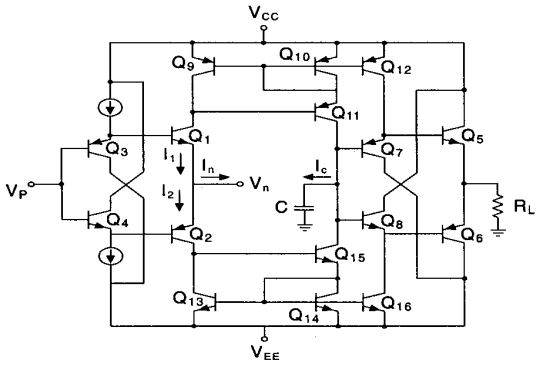


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FIGURE 3.

Let's take a closer look at the endpoint measurement. If we could change the intercepts or the shape of this "parabola," we could come up with just about any number for DG and DP we wished (see *Figure 3*). If one could change the bias current in a typical complementary emitter follower output stage (*Figure 4*), this can be accomplished.

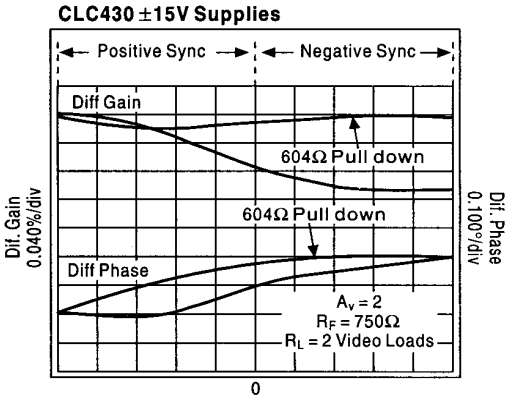
Even complementary bipolar processes leave something to be desired in PNP and NPN matching. The PNP is better than a lateral PNP, but still worse than the NPN. Beta, for one thing, and Early voltage, for another, are not as good as in the NPN. The PNP is the limitation in the output stage. Many Comlinear amplifiers specify the maximum output voltage and current capabilities based on PNP. Often the device is significantly better than this especially when the output is sourcing current from the NPN. The PNP simply cannot sink an equal magnitude of current without compromising other device performance specifications. Some devices, like the CLC406, specify two output voltage ranges, e.g. +3.1, -2.7 (see*Figure 4*).



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FIGURE 4.

An old trick which can improve the situation (at the expense of burning more circuit power) is to place a "pull-down" resistor on the output. This increases the collector current in the NPN and relieves the burden on the feeble PNP. Notice the effect of this pulldown resistor on DG and DP. Increasing the output stage NPN collector current flattens the DG, DP curves. It is possible to reduce the peak-to-peak DG, DP and force it to zero at the end-points. *Figure 5* shows the CLC430 driving two video loads (total R_L = 75Ω). After adding a pulldown resistor, the DG, DP went from 0.04%, 0.1° to 0.01%, 0.02°.



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FIGURE 5.

Another test method used in an attempt to measure DG and DP of individual op-amps employs a vectorscope, in spite of its limited resolution. If you assume that five amplifiers in a row each have +0.2 DG and DP, you could theoretically estimate the accumulated error of this chain. We have already seen that amps can be selected to cancel DG, DP errors, so this method is highly suspect (see *Figure 6*).

Careful reading of the data sheets from other manufacturers will reveal anomalous devices' test conditions for DG and DP. A frequent dodge is to specify a 500Ω or even a 1000Ω load. Most video designers need to know DG and DP into a 150Ω load. DG and DP frequently are not the best at a gain of two. The DUT may be "measured" in a gain of three, or another gain where DG/DP are best. Always look for the amplitude of the test signal. It is rarely specified. The proper luminance may be stated in the test conditions, but the chrominance will not (or vice versa). It should come as no surprise that an amplifier will have better DG and DP when delivering 100mV at 3.58MHz into 1kΩ.

If a manufacturer's DG, DP specifications appear to meet the required test conditions for carrier frequency, luminance levels, load and gain, there is still the question of whether the RMS, peak-to-peak or endpoint delta error is measured. This is rarely, if ever, stated. Finally, you may wish to ask for maximum guarantees on DG and DP.

National guarantees DG and DP, others offer only typical (see *Figure 7*).

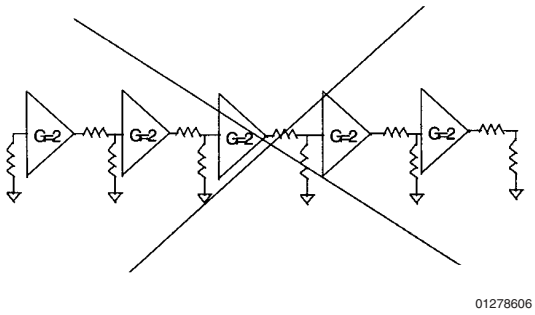


FIGURE 6.

Summary

Please read all data sheets carefully. DG and DP may not be "measured" as you expect. Consider the measurement technique, the test conditions and the guaranteed specifications. Does the data sheet really specify what you need to know?

References

1. *More Random Walks Through Science,* Robert L. Weber, editor, The Institute of Physics, Bristol, England.
2. *Television Measurements,* NTSC Systems, Margaret Craig.
3. *Video Technology Tutorial,* May 1992, Dennis Brunnenmeyer, Cedar Ridge Systems, Cedar Ridge.
4. *Operational Amplifiers, Theory and Practice,* J. K. Roberge.
5. *Solutions* with Speed 1993-1994, Comlinear Corporation.
6. *Raster Graphics Handbook*, Second Edition, Conrac Division, Conrac Corporation.

Video - Differential Gain/Phase Comparison

	1 Load		2 Load		3 Load		4 Load	
Part #	DG	Df	DG	Df	DG	Df	DG	Df
CLC231	.005	.09	.006	.10	.007	.11	.008	.14
CLC400	.025	.01	.025	.015	.025	.015	.025	.015
CLC404	.05	.03	.05	.06	.05	.10	.06	.13
CLC406	.03	.02	.03	.025	.04	.03	.04	.03
CLC409	.02	.02	.015	.025	.02	.025	.015	.03
CLC410	.02	.015	.02	.02	.03	.03	.02	.03
CLC411	.02	.05	.05	.10	.06	.19	.08	.26
CLC412	.02	.02	.02	.02	.025	.05	.03	.075
CLC414	.02	.16	.02	.18	.03	.20	.04	.20
CLC415	.02	.07	.02	.08	.02	.09	.02	.10
CLC420	.02	.14	.02	.15	.025	.15	.025	.17
CLC430	.02	.02	.02	.09	.015	.18	.02	.30
CLC431	.1	.1	.2	.2	.35	.35	.45	.45
CLC432	.1	.1	.2	.2	.35	.35	.45	.45
CLC522	.03	.07	.04	.08	.045	.09	.05	.10
CLC532	.05	.01	.11	.08	.19	.15	.34	.24
CLC533	.03	.01	.11	.09	.19	.15	.34	.24

FIGURE 7.

Note: The circuits included in this application note have been tested with National Semiconductor parts that may have been obsoleted and/or replaced with newer products. Please refer to the CLC to LMH conversion table to find the appropriate replacement part for the obsolete device.

Notes

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