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The trend toward lower power supply voltages has recently inspired the design of integrated single-supply high-frequency amplifiers. The greatest use of these circuits is in passing video signals, although there are many other applications. Unity-gain bandwidths of the new offerings are in the 90MHz–160MHz range.

The earliest single-supply IC amplifier is the LM324, developed circa 1974. This is a 1MHz op-amp that set the definition of a single-supply circuit:

> A single-supply device works with no minus supply; using 0V and typically +5V for minus and V+ supply voltages, respectively. Inputs will linearly comply with 0 (ground) to some voltage approaching V+. Outputs will provide from 0V or nearly so to a voltage approaching V+.

Figure 1 shows circuitry at the input of these amplifiers. The input PNP differential pair is followed by an NPN folded cascode that performs level-shifting. The cascode emitter resistors have typically only 200mV across them, allowing the input PNP bases to comply with ground-level inputs, and even a bit below ground, without severe saturation. For positive swings, the current-source transistors and the V_{BE}'s of the input transistors set the input positive headroom, between 1.1V and 1.7V. The DC input offset will not degrade until input swings are within millivolts of the headroom limits, but AC characteristics can vary hundreds of millivolts from the limits. Usually bandwidth is the non-constant parameter, but in some circuits transient responses are also distorted.

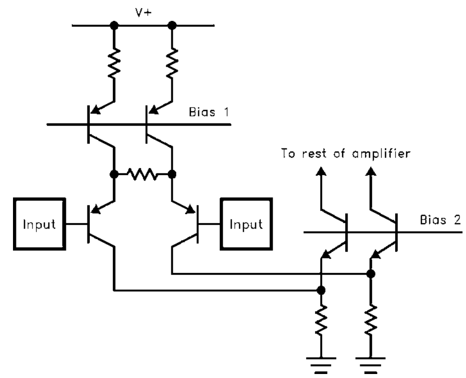

FIGURE 1. TYPICAL SINGLE-SUPPLY AMPLIFIER INPUT STAGE

The maximum output swing below V+ usually is about the same as input headroom. A complication is that output stages in bipolar technology cannot inherently sink current all the way to ground, and minimum output low swing depends on the polarity and magnitude of load current. A grounded pull-down resistor is often used to help the output to drop all the way to ground. Figure 2A shows an NPN/PNP output stage. A load resistor keeps the output NPN properly biased all the way to ground, but the output PNP has turned off well above. Figure 2B shows an all-NPN output stage. This design cannot swing as close to ground as 2A with a pull-down resistor, but it can swing somewhat lower than 2A when sinking load current. The all-NPN circuit does exhibit generally greater distortions and load capacitance sensitivity than the NPN-PNP design.

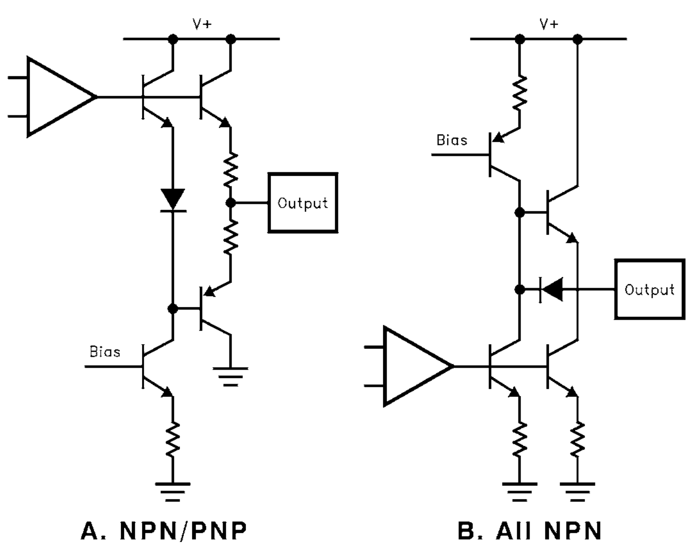

FIGURE 2. TYPICAL SINGLE-SUPPLY OUTPUT STAGES

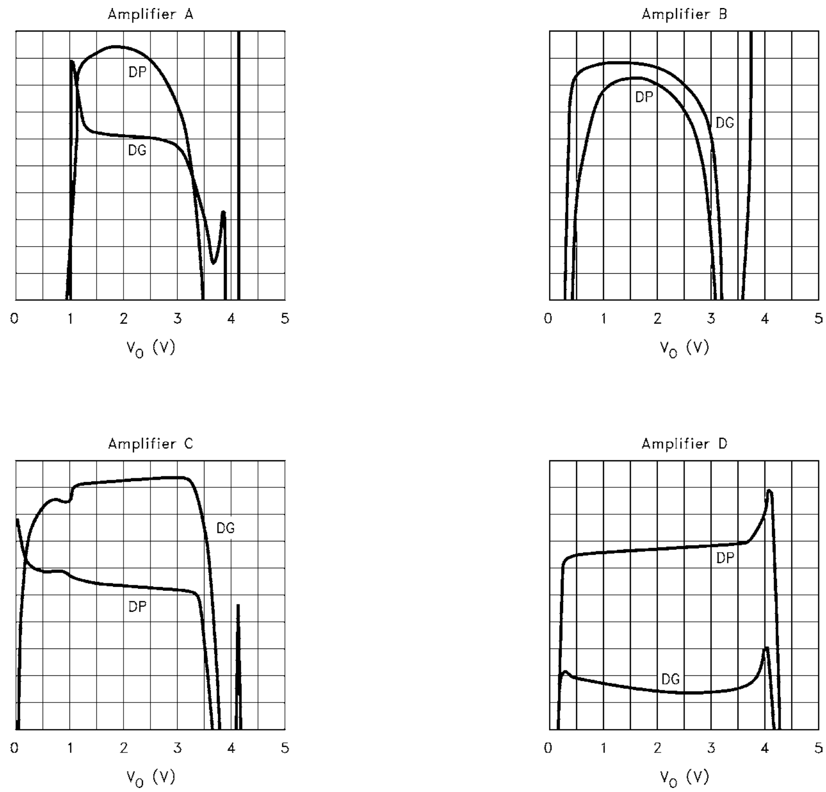

FIGURE 3. DIFFERENTIAL GAIN AND PHASE ERROR, A_V = 1, R_L = 500, V_{IN} = 0V–5V, DG = 0.2%/DIV, DP = 0.2°/DI

Output linearities are generally quite good within the headroom range for DC signals, but high AC distortions occur when levels approach clipping. Figure 3 shows the differential gain and phase errors, that is, the constancy of small-signal gain and phase as DC level varies, for several commercial amplifiers. Amplifier A is an EL2044, a general-purpose video amplifier; B is an EL2210, a low-cost video amplifier; C is an EL2150, a 125MHz true single-supply video amplifier; and amplifier D is another vendor's 90MHz single-supply amplifier. In Figure 3, all amplifiers are wired for a gain of +1, the input is a 50mV$_{P-P}$ 3.58MHz AC signal with DC offset sweeps from 0V to 5V, the load is 500Ω to ground, and the supply voltage is +5V. Here is a summary of amplifier swings, with 0.4% or 0.4° gain and phase deviations from the center of the span:

TABLE 1. AMPLIFIER OUTPUT SWINGS [V] FOR 0.4% OR 0.4° DEVIATION FROM CURVES IN FIGURE 3

AMPLIFIER	LOW SWING	HIGH SWING	SPAN CENTER	TOTAL SPAN
A	1.05	3.00	2.03	1.95
B	0.65	2.80	1.73	2.15
C	0.22	3.50	1.86	3.28
D	0.22	4.10	2.16	3.88

For small signals, differential gain is similar to linearity error or harmonic distortion, although the scale factor between them is not 1:1. Differential phase is a specification important to preserving color quality in NTSC video. Differential gain and phase errors of 0.5% and 0.5° are sufficient for consumer or overlay NTSC video; 0.1% and 0.1° or better is required for professional NTSC video; and 0.5% gain linearity is sufficient for high-quality component video signals.

Note that each amplifier has a unique set of swings and center of span. Note that the single-supply amplifiers simply cannot operate linearly all the way to ground. If the maximum linear spans are to be obtained, the input signal must be offset by the Span Center. If offset, all of these amplifiers can pass an NTSC video signal with low distortion, even the non-single-supply models.

Figure 4 shows the amplifiers wired for a gain of +2 and driving a 150Ω load to ground, as in driving a back-terminated 75Ω cable service. The input is a 50mV$_{P-P}$ 3.58MHz AC signal with DC offset sweeps from 0V to 2.5V. The amplifiers all have more distortion with the heavier load:

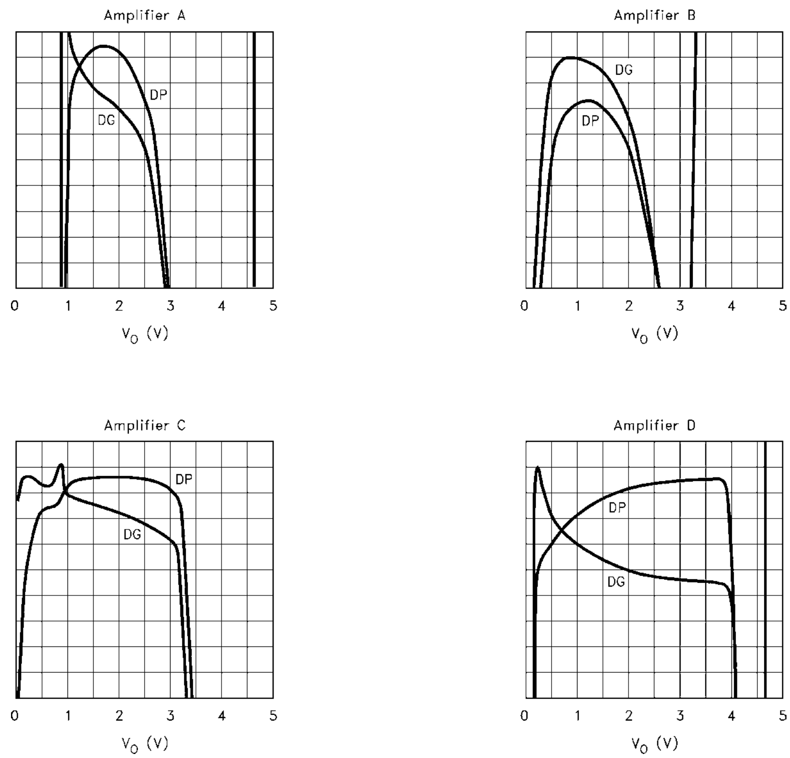

FIGURE 4. DIFFERENTIAL GAIN AND PHASE ERROR, A_V = 2, R_L = 150, V_{IN} = 0V–2.5V, DG = 0.1%/DIV, DP = 0.2°/DIV

TABLE 2. AMPLIFIER OUTPUT SWINGS [V] FOR 0.4% OR 0.4° DEVIATION FROM CURVES IN FIGURE 4

AMPLIFIER	LOW SWING	HIGH SWING	SPAN CENTER	TOTAL SPAN
A	1.05	2.50	1.78	1.45
B	0.50	2.15	1.33	1.65
C	0.30	3.13	1.72	2.83
D	0.45	4.00	2.23	3.55

The amplifier A cannot linearly swing the 2V span of double-sized NTSC signal and is not applicable to this task. Amplifier B can be used if the input is offset such that the worst distortion occurs in the non-critical sync portion of the signal. Neither of the true single-supply amplifiers will have trouble with video signals, and the output can be allowed to go all the way to ground in the sync tip.

The worst trouble occurs when the load is capacitor-coupled. This is very common for instrument inputs and outputs. In this case, AC load currents can be positive or negative. Figure 5 shows the performance of the amplifiers driving 300Ω to ground and 300Ω to V+, emulating a capacitor-coupled 150Ω load.

Generally, then, in single-supply amplifier circuits, signals will be offset above ground with capacitor coupling and DC-restoration used to regain offset levels.

TABLE 3. AMPLIFIER OUTPUT SWINGS FOR 0.4% OR 0.4° DEVIATION FROM CURVES IN FIGURE 5

AMPLIFIER	LOW SWING	HIGH SWING	SPAN CENTER	TOTAL SPAN
A	1.70	2.83	2.27	1.13
B	2.45	2.80	2.63	0.35 — requires pull-down
C	1.15	3.45	2.30	2.30 — 0.5%/0.5°
D	0.73	2.00	1.36	1.27

Again amplifier A does not have enough swing for our video signal. Amplifier B fails altogether without a pull-down resistor. With the pulldown B's performance will be very close to that of Figure 4. Amplifier C shows crossover distortion but has a good swing, if we allow the error to increase to 0.5% and 0.5°. Amplifier D has terrible crossover distortion and a very restricted output range, so is useless for driving bi-directional load currents.

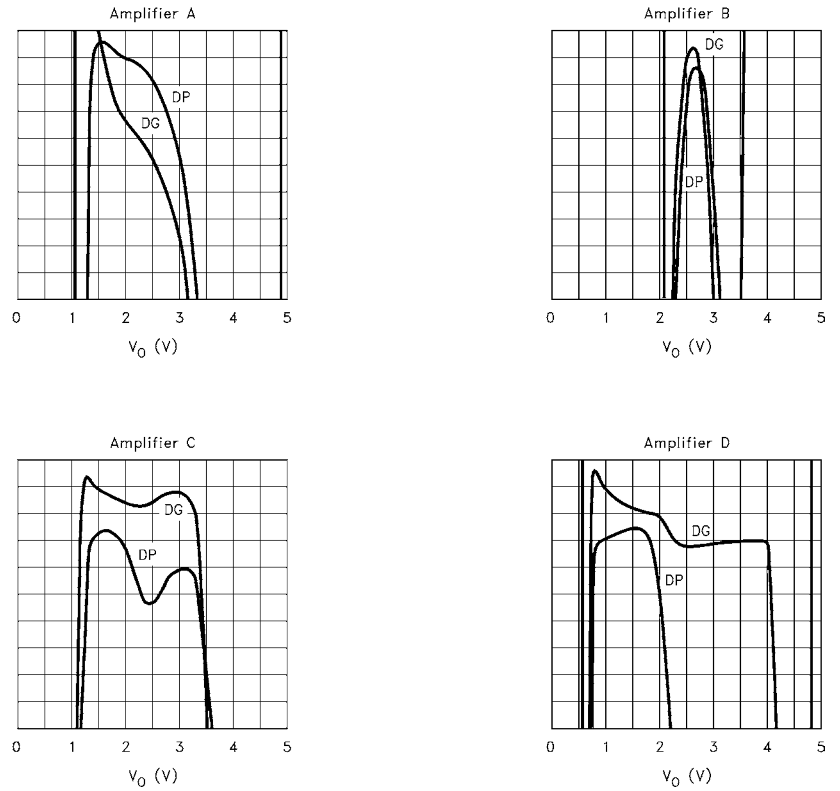

FIGURE 5. DIFFERENTIAL GAIN AND PHASE ERROR, A_V = 2, R_L = 300 TO V_{CC} AND 300 TO GROUND, V_{IN} = 0V–2.5V, DG = 0.1%/DIV, DP = 0.2°/DIV

The transient response curves shown in Figure 6 present another approach to studying distortion when the output is driven toward ground. All amplifiers are wired in unity gain configuration and powered with a +5V single supply and drive 150Ω load. The input is a 1MHz $4V_{P-P}$ sinewave with its minimum voltage at 0V. Amplifier

A output clips are around 250mV. Amplifiers B and C output linearly go down to 50mV above ground. Amplifier D, even though it can reach 80mV from ground, shows a saturation recovery step at 475mV. Voltage clipping and saturation recovery directly translate to differential gain and phase errors.

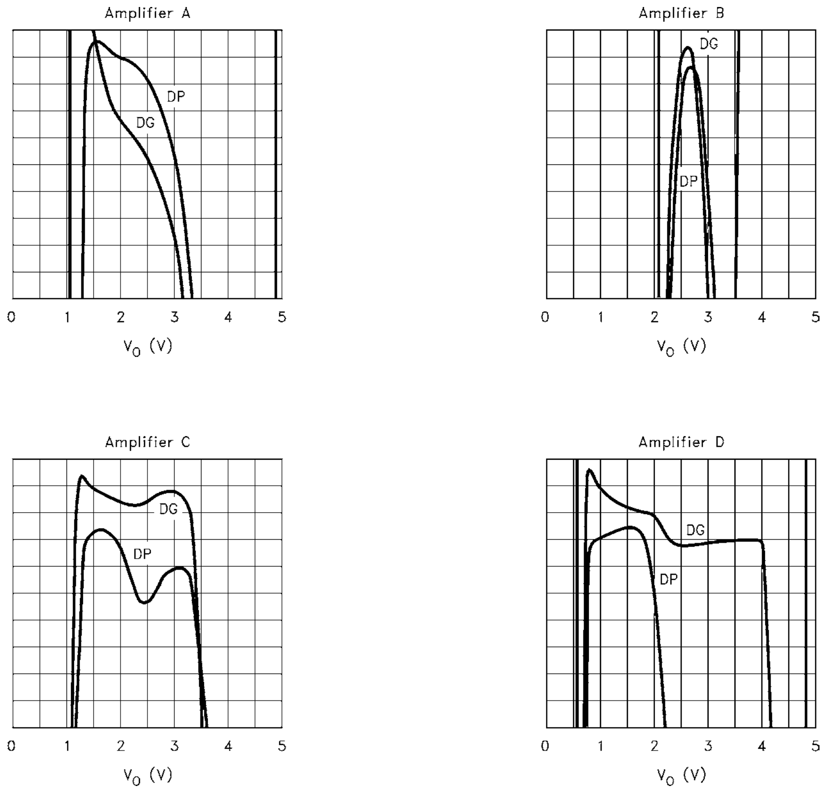

FIGURE 6. TRANSIENT RESPONSE, A_V = 1, R_L = 150

Conclusion

High-frequency op-amps' linearities suffer greatly in single-supply service. To optimize video performance it is helpful to level-shift the signal, possibly with a DC-restore system. Specially designed single-supply amplifiers offer the widest swings, but have serious limitations and behaviors that must be measured individually.