Fine Harmonic Distortion Measurements in the Megahertz Range

Application Note | March 20, 1998 | AN1098

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Harmonic distortion measurements of amplifiers is easily accomplished using a commercial test set which includes a low-distortion oscillator. These units work only up to 100kHz or less; at higher frequencies, a low-distortion oscillator and spectrum analyzer are employed. Unfortunately, commercial sinewave oscillators have no better than -56dBc harmonic content (0.16%), and spectrum analyzers offer no better than -72dBc (0.025%) internal distortion levels. This author had to test amplifier IC's to -80dBc (0.01%) levels at 2MHz, and couldn't buy general-purpose lab equipment to do the job at any price. This article shows the circuits made to do the job.

Referring to Figure 1, we will make a clean sinewave source to drive the **D**evice **U**nder **T**est (DUT). Its output will pass through a fundamental reject filter so that the harmonics may be amplified without overload from the high-amplitude fundamental. Having stripped most of the fundamental away, the reject filter's output may be viewed on a spectrum analyzer or passed on to individual harmonic measurement sections for fast automated testing.

The sinewave applied to the DUT must have less than -80dBc distortion. This is pretty hard to accomplish, since we will generate it with active semiconductors whose distortion levels are too high. About the best unfiltered output distortion level we can obtain from transistor amplifiers is -60dBc (ref. 1). We cannot use an active filter to clean up the harmonics further, because again no amplifiers can be used that will not add more distortion. A simple passive filter is used to bring distortion below -80dBc.

Figure 2 shows the oscillator schematic. It produces 1 VMRS into a 500Ω load. Note that the simple passive network is not a fancy N-th-order filter of some precise characteristic; it is simply a series tuned circuit and a parallel trap at the output, both resonant at the oscillator frequency. The Q's of the circuits are intentionally low, around 10 with the 500Ω load, to make them non-critical with respect to tuning. Two ranks of tuned circuit give a harmonic rejection of roughly Q^2, more than enough to achieve the desired output distortion level. The loss of the filter does not effect the output level; it is actively stabilized, even if a 50Ω load is used.

The EL4451 in Figure 2 is a variable-gain amplifier. It has two inputs: REF, which has a low distortion gain of 1 to the output; and V_{IN}, which is a variable-gain input controlled by the Gain inputs. A crystal is connected from the output back to the REF input, loaded by 330Ω + 160Ω. The crystal has about 150Ω series impedance at resonance, so the voltage division through the crystal prevents sustained oscillation. The extra gain required for oscillation comes from the V_{IN} path, and if the Gain input level is sufficient the EL4451 will oscillate.

This oscillation will grow uncontrollably until clipping occurs, so an EL4450 is used as an amplitude stabilizer. The EL4450 is a four-quadrant multiplier, and its X- and Y-inputs are wired to the filtered oscillator output. In the EL4450's multiplier is developed a level proportional to V_{OUT}^2, and this is compared to a reference level at the REF input. The FB terminal is connected to DC ground, but it also is connected to C3 to form a pseudo-integrator with the output amplifier. Thus, the output is approximately the integral of the RMS of the oscillator output level minus the DC reference. If the oscillator output is greater than the reference, the EL4450 output ramps positive and reduces the EL4451 gain via its Gain-terminal. If the oscillator output is less than the reference, the integrator output ramps negative and raises the EL4451 gain. Thus the EL4450 acts as a level detector and servo loop integrator. Amplitude modulation noise is extremely low with this servo.

The pseudo-integrator in the EL4450 output circuit includes a zero between C3 and its 10K resistor. This is cancelled with an additional pole from C4 and the parallel of its 20K resistors.

The crystal can be replaced by a series LC circuit. It is very difficult to make this circuit provide widely variable output frequency, but it can easily be switched with rotary switches and multiple crystals and output filters. Both input and output terminals of the filter must be switched. Other load impedances can be driven, but the output filter must be redesigned. Generally, at resonance $X_{L1} = X_{C1} = R_L * Q$ and $X_{L2} = X_{C2} = R_L/Q$.

Figure 3 shows the fundamental reject circuitry. Because in the author's test setup the DUT produces a 9VRMS fundamental amplitude, the L3-C3-L4-C4 filter attenuates it immediately so that the first amplifier is not overloaded. The EL2074 is a very low distortion wideband amplifier, but we still have to control the levels. The amplifiers provide a total gain of 100 for the harmonics to the spectrum analyzer or harmonic select sections, and each stage includes a fundamental-reject filter.

The output of the first amplifier still has an attenuated fundamental level of around 900mVRMS, so the second filter knocks the fundamental down further to around 9mVRMS. The final output has a fundamental down by about 80dB, and harmonics up by 40dB, easily viewed on a spectrum analyzer. Calibration is simple: just provide an input at some frequency greater than the fundamental and find the gain with an oscilloscope, or better yet use a network analyzer to measure gain over frequency. Set amplitudes so that no more than 1VRMS is outputted.

SW1 is used to select high or low gain for the harmonic select and measure sections, due to their restricted dynamic ranges. A switch can be used, but the author used a relay. To preserve distortion and noise quality, semiconductor analog switches or multiplexed-amplifiers should not be used.

The EL2120 amplifier buffers the final filter and provides a gain of +2 to compensate for the loss of the back-matched 50Ω load termination.

Figure 4 shows a harmonic select channel. The output from SW1 routes through the L9-C9-L10-C10 network which passes the desired harmonic frequency. The EL2074 amplifies this harmonic and drives another filter also tuned to the desired harmonic. This highly selected harmonic is passed a fast comparator and then to the EL4450 four-quadrant multiplier. The multiplier's input signals are the harmonic and a clipped version of the harmonic. This clipped signal is the same as the sign of the harmonic, so the multiplier output is the harmonic times its own sign, or the absolute value of the harmonic. A simple RC filter passes the DC component, which is a linear measure of the selected harmonic. The 180Ω–10pF components provide a simple time delay equal to that of the comparator to balance the phase of the multiplier inputs, improving accuracy at higher frequencies.

The design of L's and C's in the harmonic select section is similar to that of the other sections, where at the harmonic frequency $X_{L9} = X_{C9} = X_{L11} = X_{C11} = 250\Omega * Q$ and $X_{L10} = X_{C10} = X_{L12} = X_{C12} = 250\Omega/Q$.

Unless 5% L's and C's are used and parasitic capacitances are kept to less than 2pF, the networks will have to be tuned. The author used a network analyzer, measuring the output of an amplifier following a tuned circuit so as not to load and de-tune it. Either the inductor or the capacitor can be adjusted; if the capacitance value is less than 100pF a variable trimmer can be used in parallel with a fixed capacitor, otherwise a slug-tuned variable inductor can be used. It seems archaic to have to adjust LC circuits in this era of IC's, but they do allow the lowest distortion measurements.

It is completely practical to use multiple-pole rotary switches to allow different operating frequencies, seven poles being adequate for the oscillator and fundamental reject section. A pole can be saved by wiring all crystals together at the EL4451 output. The filters should be kept as physically separate as possible.

This project provided a lab test device better than commercial units. It does require assembly and adjustment, but it produces solid results.

References.

1. Harvey, Barry, “Oscillators Blend Low Noise and Stable Amplitude”, Microwaves and RF, Oct. 27, 1994, pp125–129.

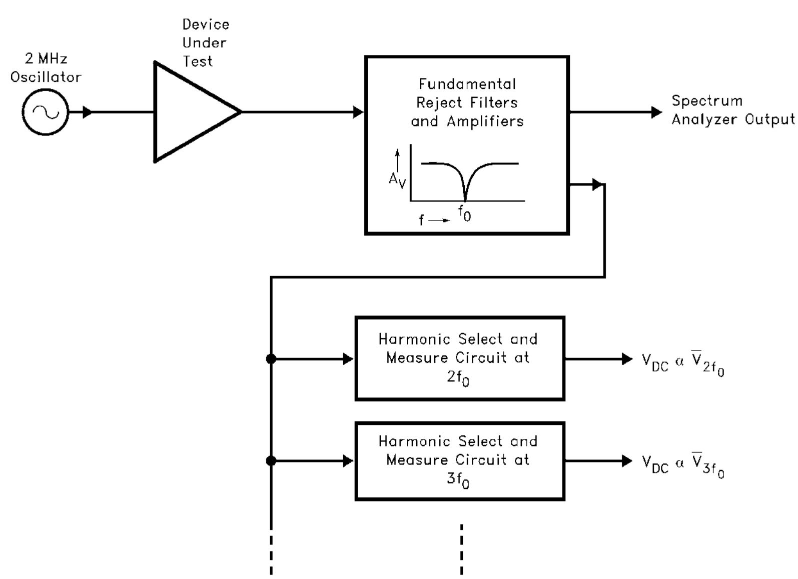

FIGURE 1. BLOCK DIAGRAM OF DISTORTION MEASUREMENT SYSTEM

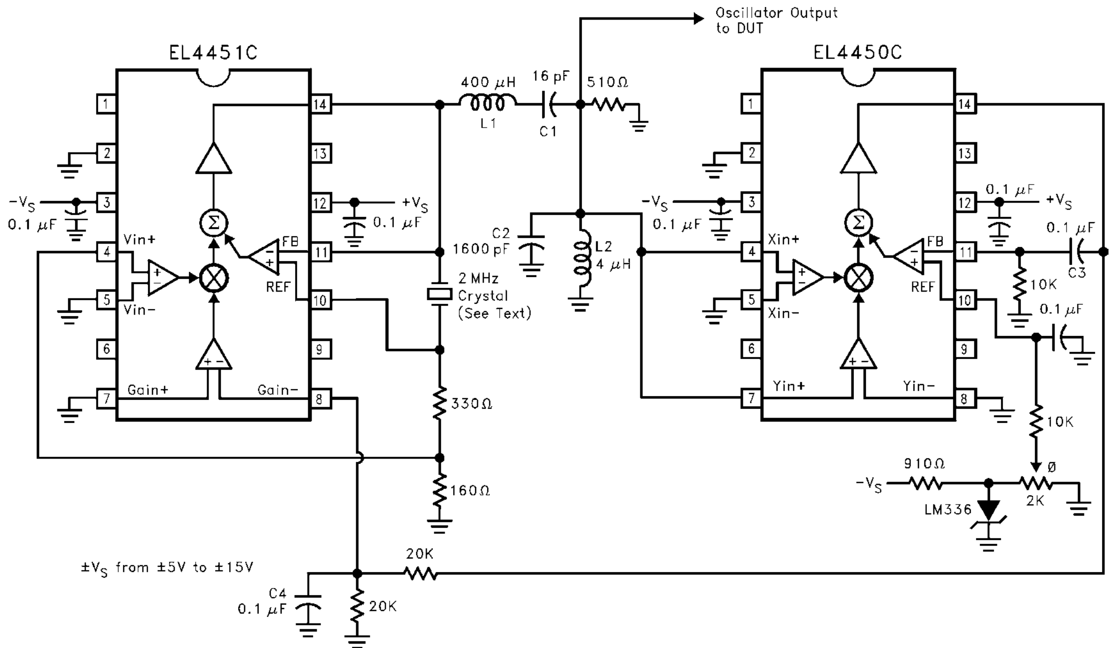

FIGURE 2. LOW-DISTORTION OSCILLATOR

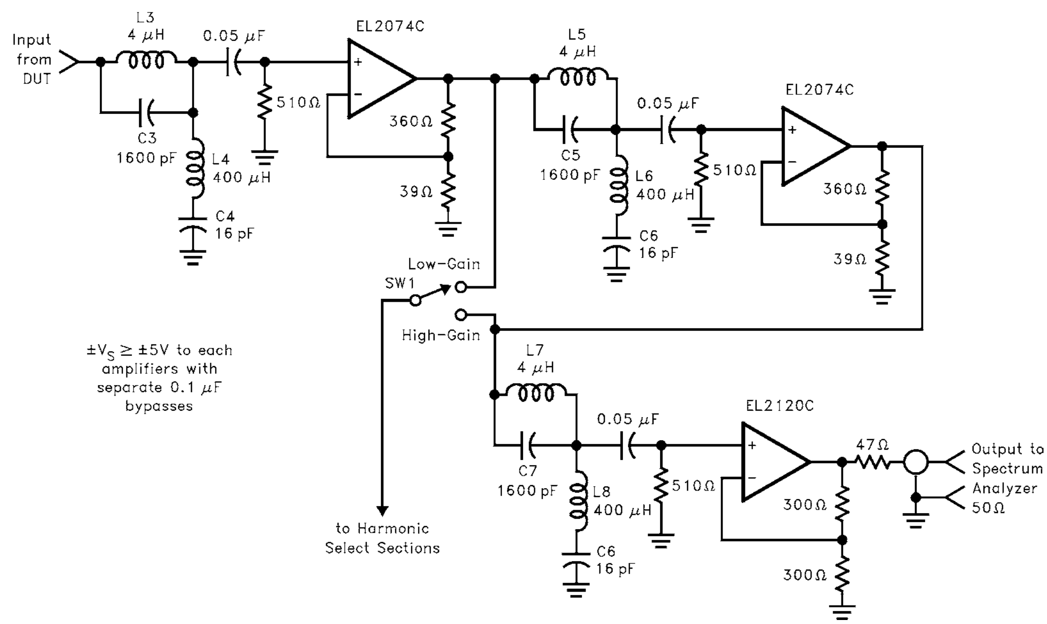

FIGURE 3. FUNDAMENTAL REJECT FILTERS AND AMPLIFIERS

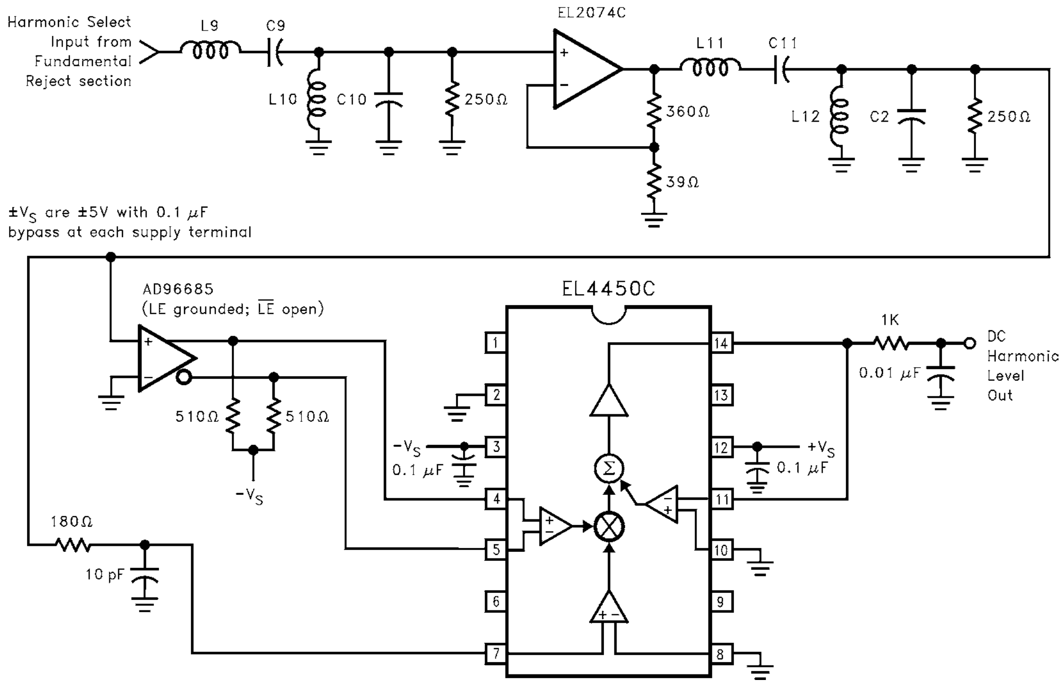

FIGURE 4. HARMONIC SELECT AND MEASURE SECTION