A Simple Notch Type Harmonic Distortion Analyzer

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Nov. 28, 2009, rev. Nov. 29, 2009

Introduction

This note describes a simple notch type harmonic distortion analyzer that can be constructed with basic parts. It is intended for use in situations where the expense of a professional distortion analyzer can not be justified. This analyzer is capable of measuring sine wave harmonic distortion down to about 0.1 percent depending on the quality of the sine wave signal source. This analyzer can only measure the distortion at a single frequency, ~1,000 Hz for the components shown.

Theory of Operation

Distortion is generally caused by a non-linear transfer function in an amplifier. The alterations to the wave shape of a sine wave by a non-linear transfer function generate harmonics of the sine wave. The degree of distortion can be measured by determining the ratio of the harmonic amplitudes to the fundamental. A lower ratio indicates lower distortion. Ideally the ratio is zero.

By definition, harmonic distortion is the ratio of the rms harmonic content of a distorted sine wave to the rms of the fundamental. The notch filter distortion measurement concept operates on a modified definition using the ratio of the amplitude of the signal with the fundamental removed by a notch filter to the amplitude of the full signal. When the harmonic distortion is less than about ten percent the difference between the two concepts is small. Simplicity is what makes the notch filter approach attractive. The harmonic distortion in percent is simply 100% multiplied by the ratio of the signal with the fundamental notched out to the total signal amplitude. The bandwidth of the notch must be small enough so that the second harmonic is barely attenuated. This is achieved with a Q of resonance of around 3. The frequency response of the basic twin-tee notch filter with a Q of 0.25 is shown in Figure 1. The bandwidth is too broad for accurate measurement as there is significant attenuation of many harmonics. The frequency response of the twin-tee with positive feedback to boost the Q up to 3 is shown in Figure 2. For this case the attenuation of the harmonics is insignificant.

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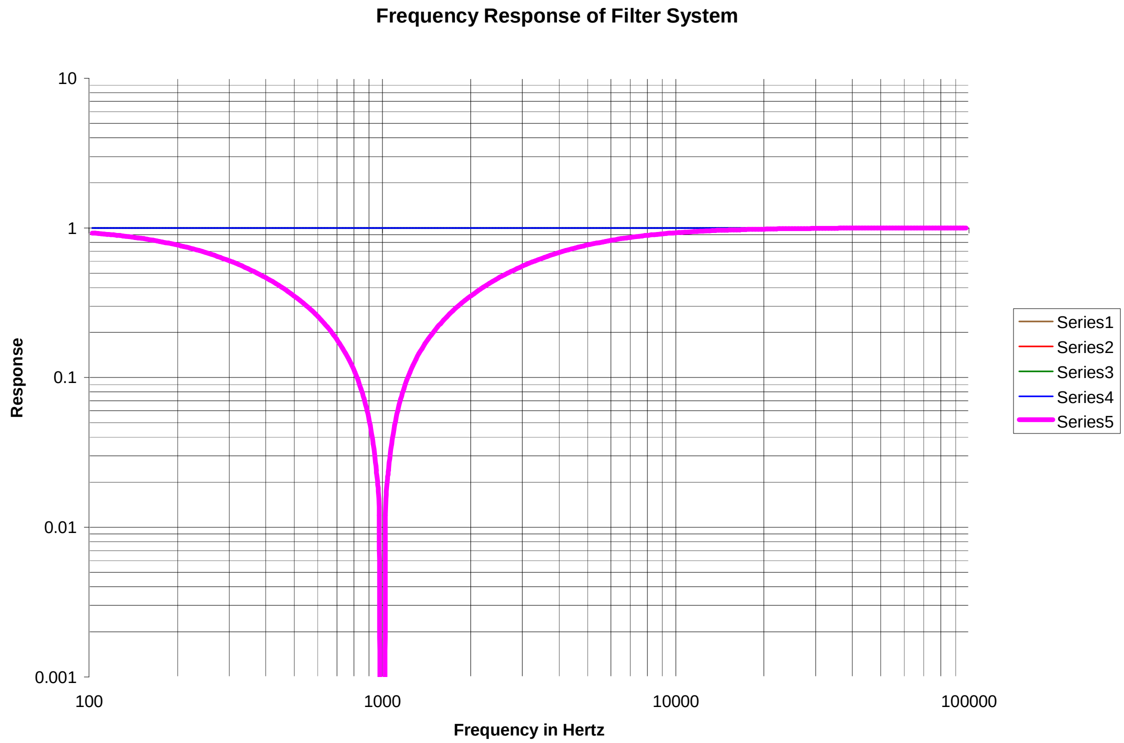

Figure 1: Frequency Response of Basic Twin-Tee Notch Filter, Q = 0.25

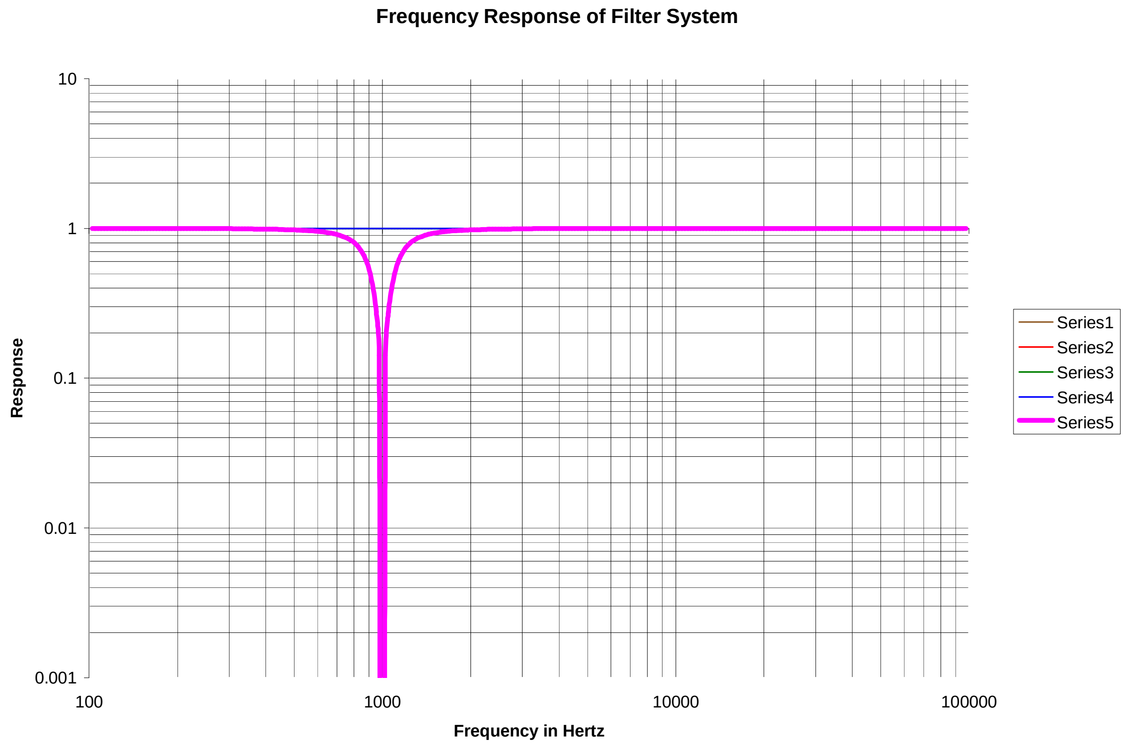

Figure 2: Frequency Response of Boosted Q Twin-Tee Notch Filter, Q = 3

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For distortion testing it is important to begin with an ultra low distortion sine wave source to apply to the amplifier or electronics under test. Ideally, the distortion in the source should be less than 0.01 percent. Standard function generators have a sine wave distortion around 1 percent or more and are not suitable unless a significant low-pass filter is used to reduce the harmonics to an acceptable level.

Circuit Description

The schematic diagram of the distortion analyzer is shown in Figure 3.

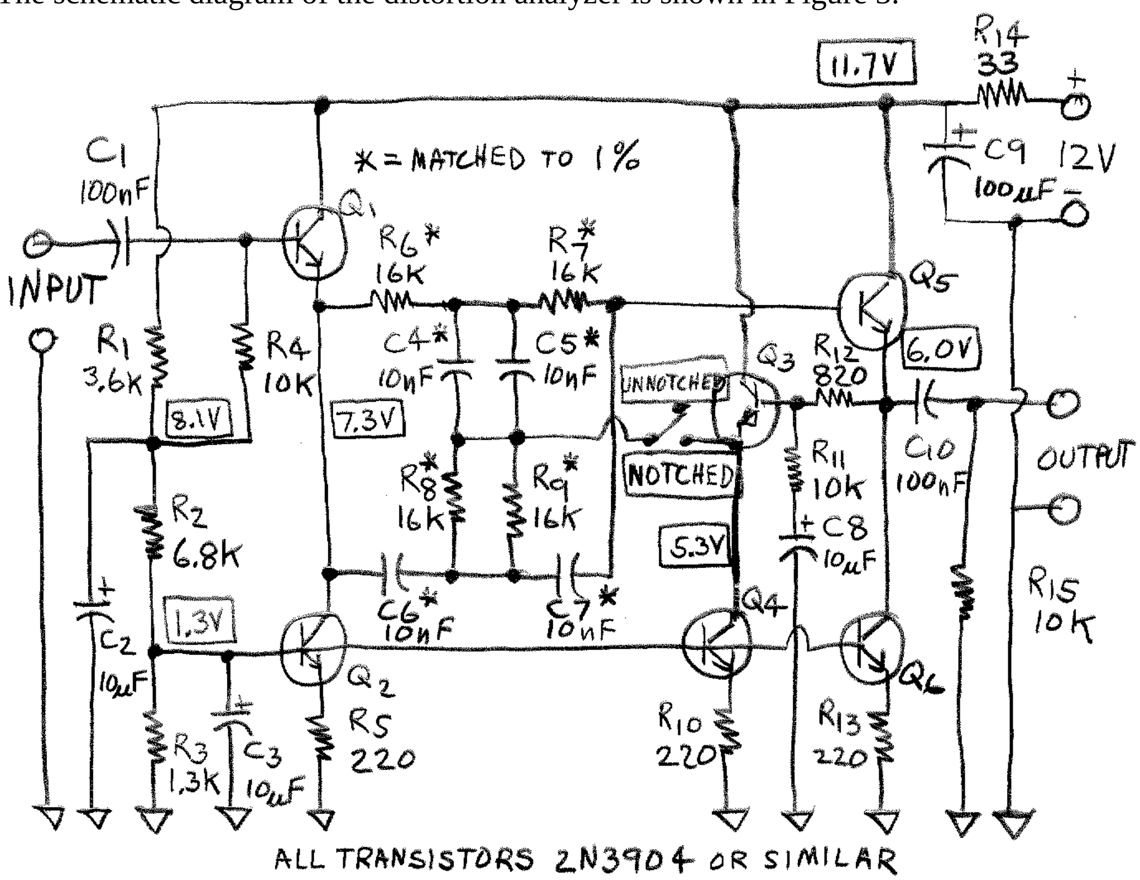

Figure 3: Schematic Diagram

The circuit consists of a unity gain input buffer, a twin-tee notch filter, a unity gain output buffer, and a buffered positive feedback factor to boost the Q of the twin-tee circuit. The Q of an un-boosted twin-tee is 0.25. With the positive feedback used in this circuit the Q is increased to around 3 which is adequate for the measurement process. The notch frequency of the twin-tee filter is given by:

$$Fn = \frac{1}{2*\pi*R*C}$$

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Current sink biasing of 3 mA is used for all of the transistor amplifiers for low distortion. The DC current in the emitter is significantly larger than the peak AC signal current thus insuring high linearity.

Specifications

Notch frequency	~1,000 Hz
Notch depth	>60 dB if components are carefully matched
Minimum detectable distortion	~0.1% if sine wave source distortion < ~ 0.03%
Maximum input amplitude	~2 Vrms
Recommended input amplitude	0.5 to 2 Vrms
Input impedance	~10,000 ohms
Power supply voltage	12 volts (15 volts can also be used)
Power supply current	approximately 10 mA

Construction

The transistors can be any general purpose NPN type such as 2N3904. The four resistors and four capacitors in the twin-tee circuit should be matched to within 1 percent of each other. It is not necessary that the actual component values be exact to the marked values such as 16K and 0.01 uF. Rather, it is important that they all be the same value whatever that is. Matching enables the notch to be very deep – a requirement for measuring low distortion. The actual component values determine the frequency of the notch which only needs to be nominally rather than exactly 1,000 Hz.

It is recommended that the electronics be built in a small metal box with binding posts for input, output and an external 12 volt power supply. The circuit can be constructed as point-point on terminal strips or perf board. In all cases clip on heat sinks should be used on the component leads to prevent the components from exposure to excessive heat from the soldering process as that could disrupt the required matching.

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Checkout

1. Connect a sine wave generator to the input of the analyzer and an AC voltmeter to the output.

2. Set the frequency of the sine wave to nominally 500 Hz and adjust the output level so that the AC voltmeter indicates 1.0 Vrms.

3. Tune the signal generator to 845 Hz and confirm that the AC voltmeter indicates between about 0.6 and 0.8 Vrms. See note below.

4. Tune the signal generator to 1,180 Hz and confirm that the AC voltmeter indicates between about 0.6 and 0.8 Vrms. See note below.

5. Tune the signal generator to 2,000 Hz and confirm that the AC voltmeter indicates very close to 1.0 Vrms.

6. Tune the signal generator to near 1,000 Hz and then carefully fine tune the frequency for the minimum reading on the AC voltmeter. The minimum reading should be no more than 1 mVrms. Note that using a standard function generator with typical sine wave distortion of 1 percent will result in about 10 mVrms for this test. If that is the case then the distortion analyzer is working fine. A lower distortion sine wave source is needed.

Steps 3 and 4 confirm that the notch Q is correct. If necessary the Q can be increased by lowering the 820 ohm resistor to 750 or perhaps 680 ohms. Too low Q is indicated by the voltage level being less than 0.6 volts. Too high Q is indicated by the voltage level being greater than 0.8 volts. It is not likely that the Q will be too high but if so the 820 ohm resistor can be increased to 910 or perhaps 1,000 ohms. Relatively small adjustments in this resistance have a significant effect on Q.

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Operation

1. A low-distortion sine wave generator is connected to the input of an amplifier under test. The analyzer input is connected to the output of the amplifier under test. An AC voltmeter (preferably one that measures true rms, but average responding provides reasonable results) is connected to the output of the distortion analyzer.

2. With the notch switch in the UNNOTCHED position, the sine wave generator output level is adjusted so that the AC voltmeter indicates between 1 and 2 volts rms. The frequency should be around 1000 Hz but that will be fine tuned in the next step. Record the voltage as measured by the meter and refer to it as $V_{UNNOTCHED}$.

3. Set the notch switch to the NOTCHED position and fine adjust the frequency of the sine wave generator around 1000 Hz for the minimum indication on the AC voltmeter. This will take very fine control to achieve as the frequency must be set to within 1 Hz of the notch frequency. Record the voltage as measured by the meter and refer it as $V_{NOTCHED}$.

4. Calculate the distortion as

$$\text{Distortion in percent} = \frac{V_{NOTCHED}}{V_{UNNOTCHED}} * 100\%$$

The distortion level of the sine wave source should be directly measured as that represents a floor to how low a level of distortion can be detected in the electronics under test. If the distortion measurement of the electronics under test is similar then the distortion of the sine wave source is dominating the measurement.

As an example, a sine wave is applied to the distortion analyzer. With the notch switch in the UNNOTCHED position the AC voltmeter indicates an amplitude of 1.0 Vrms. With the notch switch in the NOTCHED position and after fine tuning the signal source the minimum indication on the AC voltmeter is 30 mVrms. Thus the distortion is (0.03/1.0)*100% = 3%. This is a level that can only barely be seen by a trained eye viewing an oscilloscope display. It is also a level that is not audible to many people as the total harmonic amplitude is 30 dB below the fundamental or about 0.1 percent of the total power. However, trained ears can detect harmonic distortion below 1 percent.

An oscilloscope can be connected to the output of the analyzer to observe the distortion waveform. That can be interesting and educational.

It is interesting to experiment with the analyzer by using square waves and triangle waves. From the Fourier series the distortion of a square wave is 46.7 percent and 12.1 percent for a triangle wave. Even using a true rms AC voltmeter this instrument will show a significantly lower value for the square wave and a somewhat lower value for the triangle wave because of the modified method of measurement as discussed in the theory of operation section. The triangle wave is a good reference point to understand operation of this instrument.

Improvements

A weakness of this method of measuring distortion is that extraneous signals such as noise, AC line pickup, etc. corrupt the measurement causing the indicated distortion to be higher than actual. These effects can be reduced by adding a broadband filter between the output of the analyzer and the AC voltmeter. For good results the filter should be of at least second but preferably fourth order on the low and high cut-off frequencies. The low frequency filter should not attenuate 1 kHz by more than a factor of about 0.98 and the high frequency filter should not attenuate 15 kHz by more than a factor of about 0.98.

Before adding a filter the AC voltmeter reading should be noted with no signal applied to the electronics under test (notch switch in the UNNOTCHED position). Ideally, the indication would be 0.0 mV but realistically it may be in the low single digit millivolts which is acceptable for measuring distortion down to around one percent. If the level is higher then a filter may be helpful.

A low-pass filter can also be added to the output of the sine wave generator to reduce the level of harmonics applied to the amplifier under test. The filter should have a cut-off frequency somewhat higher than 1 kHz and should be of at least second order.

Because the output amplitude of the distortion analyzer can be fairly low an external amplifier between the output and the meter can improve sensitivity. Any distortion in that amplifier is of no consequence provided it is relatively low (<~5%) as the frequency selective process is prior to the amplifier.