Audio Math in QA40xPlot

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Fundamental Signal RMS Voltage

The RMS voltage at the fundamental frequency is simply the height of the fundamental frequency's bin in the FFT.

V @ Frequency

Signal RMS Voltage

The RMS voltage is calculated one of two ways. For time domain data it's just the RMS definition

$$\boldsymbol{V_{RMS}} = \frac{\sqrt{\left(\sum_{t=0}^{T} V_t^2\right)}}{n}$$

For bandlimited frequency data it's a bit different since frequencies values are like densities.

$$\boldsymbol{V_{RMS}} = \frac{\sqrt{\left(\sum_{fmin}^{fmax} V_f^2\right)}}{ENBW(windowing)}$$

ENBW is the equivalent noise bandwidth of the fft windowing method. In some ways it's a measure of how much the signal is smeared into adjacent channels. It can be calculated by

$$\boldsymbol{ENBW} = \frac{\sqrt{\left(\sum_{t=0}^{T} W_t^2\right)}}{\sum_{t=0}^{T} W_t}$$

Where W_t is the fft weight at time *t*. Note this is scale-independent of the weights.

Harmonic Distortion

Using the frequency domain results the distortion voltage, in VRMS, of each harmonic is simply the height of the harmonic bin, V @ Harmonic Frequency.

The total harmonic distortion (THD) is the RMS total distortion divided by fundamental.

$$\boldsymbol{THD} = \frac{\sqrt{\left(\sum_{t=2}^{N} V_{Ft}^{2}\ \right)}}{V_F}$$

Currently QA40xPlot uses N=7. Note that distortion spectra are clearly in-phase but the above approximation is good enough.

Intermodulation Distortion

CCIF style math for IMD

When close together fundamentals (**f_H/f_L < 2**) use the 2nd order CCIF2 or 3rd order CCIF3. QA40xPlot uses CCIF3.

CCIF2 uses a single value

CCIF2 IMD = $\frac{V_{f_H - f_L}}{V_{f_H} + V_{f_L}}$

CCIF3 uses a different single value

CCIF3 IMD = $\frac{\sqrt{V_{f_H-f_L}^{2} + \left(V_{2f_L-f_H} + V_{2f_H-f_L}\right)^2}}{V_{f_H} + V_{f_L}}$

SMPTE/DIN IMD (or MOD IMD)

When the fundamentals are far apart (**f_H/f_L > 7**) use SMPTE/DIN math

SMPTE/DIN IMD = $\frac{\sqrt{\left(V_{fH-fL} + V_{fH+fL}\right)^2 + \left(V_{fH-2fL} + V_{fH+2fL}\right)^2}}{V_{fH}}$

RMS Power IMD

Finally, when **2 < f_H/f_L < 7** use IMD RMS power methods using RMS addition

POWER IMD = $\frac{\sqrt{V_{fH-fL}^{2} + V_{fH+fL}^{2} + V_{fL-2fH}^{2} + V_{fL+2fH}^{2} + V_{fH-2fL}^{2} + V_{fH+2fL}^{2}}}{\sqrt{V_{fH}^{2} + V_{fL}^{2}}}$

Noise Weighting Curves

From A-weighting - Wikipedia

The function(f) for C weighting is:

W_C(f)=$\frac{12194^2 * f^2}{(f^2+20.6^2)(f^2+12194^2)}$

Adding two real-axis poles to the C-weighting transfer function gives us A-weighting:

W_A(f)= $\frac{12194^2 * f^4}{(f^2+20.6^2)(f^2+12194^2)\sqrt{(f^2+107.7^2)(f^2+737.9^2)}}$

And unweighted effectively is

W_Z(f)=1.0

The weights are normalized to 1.0 at 1KHz.