TRAC Application Note AN25
Issue 1 September 1998

The TRAC Differentiate Function and High Pass Filters

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The TRAC family of totally reconfigurable Field Programmable Analog Devices offers an integrated path from signal processing problems to working silicon solutions - in minutes! Introducing a Top-Down, Structured design discipline, TRAC enables rapid implementation, prototyping and product release. Rather than designing at the component level, TRAC champions a Computational Approach. Using eight simple mathematical building-blocks, any transfer function can be implemented on TRAC, and more besides!

With a combination of programmable silicon and design software, TRAC brings a truly Integrated Route to signal processing problem solving, providing designers with benefits formerly associated only with programmable digital devices, and offering a path to Custom Silicon for higher volume users.

Introduction

The TRAC differentiate (DIF) function, (shown in Figure 1) which is one of the options of the AUX function, is a true mathematical differentiator. This note shows the differences between a true mathematical differentiator, a practical mathematical differentiator, a TRAC simulation of a high pass filter and a practical TRAC high pass filter.

The TRAC differentiate Function (DIF)

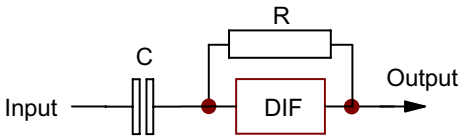

Figure1
The TRAC Differentiate Function

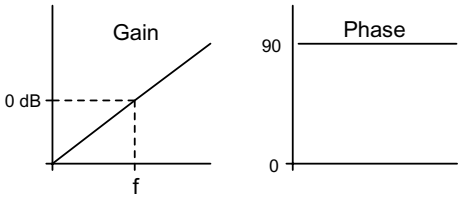

Figure 2
Gain & Phase Response of a True Differentiator

The DIF function is a true mathematical differentiator and as such has the gain and phase characteristics shown in Figure 2.

The gain is 0dB when the impedance of the capacitor (C) is equal to the resistance (R). At this point the frequency (f) will be:

$$f = \frac{1}{2\pi RC}$$

For this to occur at 10KHz, for example the value entered in the DIF cell would be 0.00001592. (This is the RC product obtained when R=7.96 kΩ and C=2 nF.) These values are used in a practical differentiator example shown later.

The phase shift is a constant 90° at **all** frequencies. The DIF function truly differentiates the input signal giving the instantaneous rate of change $\delta y/\delta t$ of the input waveform.

If the input is a sine wave the output will be a cosine wave; at a peak where the input is crossing zero and at zero when the input peaks. (See Figure 3). In actual practice all TRAC cells invert (with the exception of NIP and OFF) and the output in this case would actually be the inverse of this but it still represents the differential of the input.

A theoretical differentiator would have a very high gain at high frequencies, whereas a practical component is limited by the open loop gain of the amplifier.

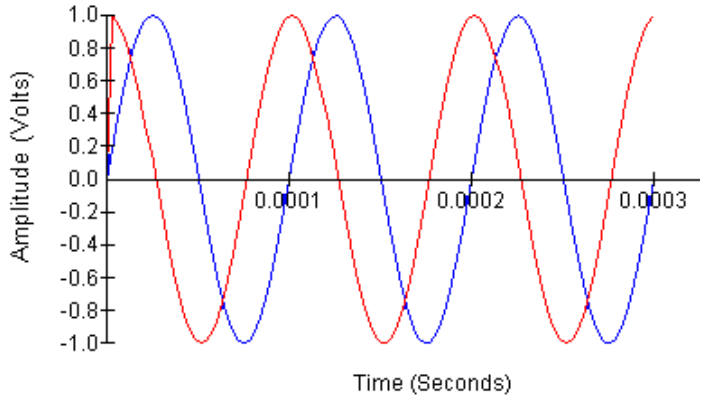

Figure 3
Input & Output Waveforms of a True Differentiator

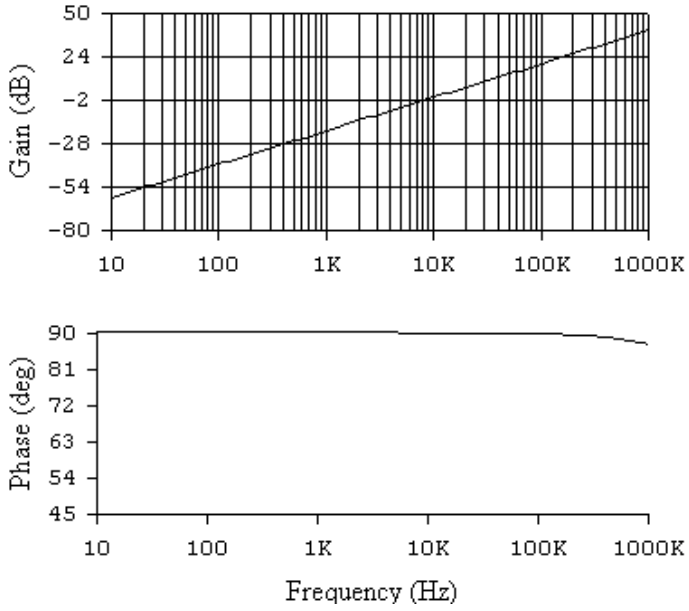

Figure 4
Gain & Phase Response of a Practical TRAC Differentiator

Figure 4 shows the gain and phase response of a differentiator with R = 7.96 kΩ and C = 2 nF. The frequency at which the impedance of the capacitor equals the resistor value is 10 kHz and at this frequency it will be noted that the gain is 0 dB.

The phase shift at 10 kHz is very close to 90°, measured as 89.9°. At 100 kHz the phase shift is 89.7° and at 1 MHz, 87° This is the result of the limited open loop gain of the practical amplifier in the TRAC cell. For use as a practical differentiator a sensible design maxim would be to choose the resistance and capacitance combination such that the impedance of the capacitor is not less that one tenth the value of the resistance at the highest frequency of operation. i.e.

$$RC = \frac{1}{0.2\pi f}$$

Then at the highest frequency of operation the gain demanded will be 20 dB and the results will approximate closely to the theoretical version of an differentiator.

True High Pass Filter

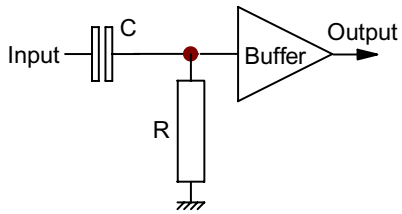

Figure 5
High Pass Filter

The gain and phase characteristics of a first order high pass filter are shown in Figure 6.

The gain for this filter will be -3dB when the impedance of the capacitor (C) is equal in value to the resistance (R). At this frequency the phase lead will be 45° and this will occur when $f=1/2\pi RC$

Figure 6 shows the results for a capacitance of 2 nF and a resistance of 7.96 kΩ (corresponding to 10 kHz)

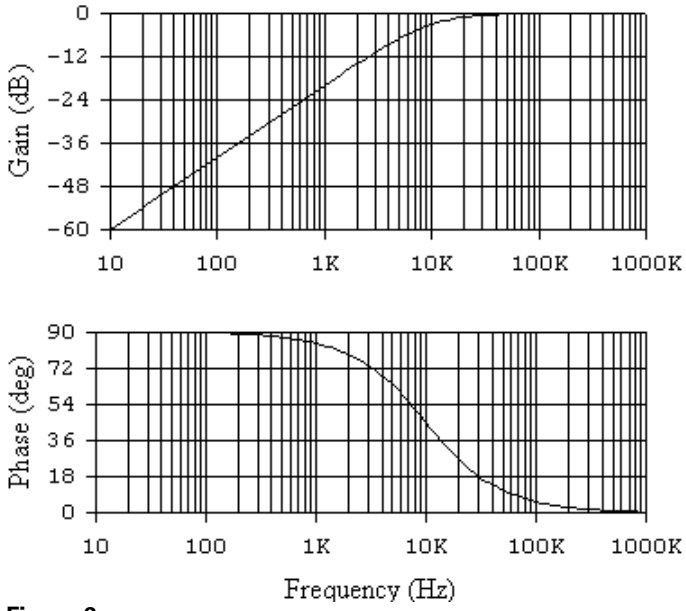

Figure 6
Gain & Phase Response of the HPF shown in Figure 5

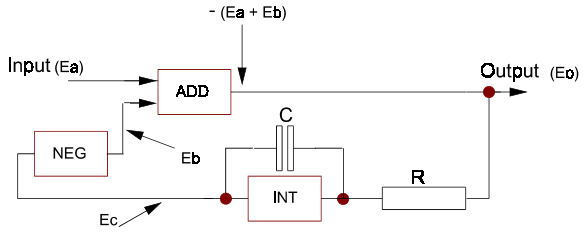

Figure 7
TRAC Software implementation of a High Pass Filter

TRAC Software Emulation of a High Pass Filter

The software emulation of the low pass filter is given in Figure 7.

If the inputs to the adder are Ea and Eb then the output Eo will be -(Ea + Eb).

Since Eb = -Ec then Eo = - (Ea - Ec) = Ec - Ea

The output of the integrator

$$Ec = -\frac{Eo}{j\omega CR}$$

Therefore $Ec = -\frac{Eo}{j\omega CR} - Ea$

Rearranging this gives

$$\frac{Eo}{Ea} = \frac{-j\omega CR}{1+j\omega CR}$$

This defines a single pole high pass filter whose characteristics are identical with those shown in Figure 6. The negative sign indicating that the waveform is inverted since the ADD function also inverts the input waveform.

TRAC Practical High Pass Filter

Whilst the above implementation of a high pass filter does work in practice it is somewhat wasteful on TRAC cells. A simpler version is shown in Figure 8.

In this case the gain for this filter will be -3dB when the impedance of the capacitor is equal to the resistance (R_1). At this frequency the phase lead will be 45° and this will occur when $f = 1/2\pi R_1C$. The high frequency gain is defined as R_2/R_1. For exact replication of Figure 5, R_1 and R_2 would be the same value but there is the added advantage of the ability to enter some gain or attenuation in this stage without the need for extra cells. Sensible gain values should be chosen bearing in mind the overall limitation of the cell's open loop gain.

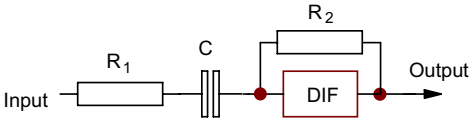

Figure 8
Practical TRAC Implementation of a High Pass Filter

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