$restart : with(plots)$

$QuantizeCoeff := (c, n) \rightarrow round(c \cdot 2^n)$

$$(c, n) \rightarrow round(c \, 2^n) \tag{2}$$

$CoeffToHex := (c, bits) \rightarrow \textbf{if } c \geq 0 \textbf{ then } convert(c, hex) \textbf{ else } convert(2^{bits} + c, hex) \textbf{ end if}$

$$(c, bits) \rightarrow \textbf{if } 0 \leq c \textbf{ then } convert(c, hex) \textbf{ else } convert(2^{bits} + c, hex) \textbf{ end if} \tag{3}$$

One pole loop filter

$tfRC := normal\left(\dfrac{R2 + \dfrac{1}{s \cdot C}}{R2 + \dfrac{1}{s \cdot C} + R1} \right)$

$$\frac{C\,R2\,s + 1}{C\,R1\,s + C\,R2\,s + 1} \tag{1.1}$$

$tf := normal\left(\dfrac{1 + s \cdot tz}{1 + s \cdot tp} \right)$

$$\frac{s\,tz + 1}{s\,tp + 1} \tag{1.2}$$

$solve(numer(tf) = 0, s)$

$$-\frac{1}{tz} \tag{1.3}$$

$solve(denom(tf) = 0, s)$

$$-\frac{1}{tp} \tag{1.4}$$

$tfzb := normal\left(eval\left(tf, s = \dfrac{2}{T} \cdot \dfrac{1 - z^{-1}}{1 + z^{-1}} \right) \right)$

$$\frac{T\,z + 2\,tz\,z + T - 2\,tz}{T\,z + 2\,tp\,z + T - 2\,tp} \tag{1.5}$$

$tfze := normal\left(eval\left(tf, s = \dfrac{\left(1 - z^{-1}\right)}{T} \right) \right)$

$$\frac{T\,z + tz\,z - tz}{T\,z + tp\,z - tp} \tag{1.6}$$

$tfznm := collect(numer(tfzb), z)$

$$(T + 2\,tz)\,z + T - 2\,tz \tag{1.7}$$

$tfzdn := collect(denom(tfzb), z)$

$$(T + 2\,tp)\,z + T - 2\,tp \tag{1.8}$$

$b0f := \dfrac{coeff(tfznm, z, 1)}{coeff(tfzdn, z, 1)}$

$$\frac{T + 2\,tz}{T + 2\,tp} \tag{1.9}$$

$$b1f := \frac{coeff(tfznm, z, 0)}{coeff(tfzdn, z, 1)}$$

$$\frac{T - 2\,tz}{T + 2\,tp} \tag{1.10}$$

$$a0f := \frac{coeff(tfzdn, z, 1)}{coeff(tfzdn, z, 1)}$$

$$1 \tag{1.11}$$

$$a1f := \frac{coeff(tfzdn, z, 0)}{coeff(tfzdn, z, 1)}$$

$$\frac{T - 2\,tp}{T + 2\,tp} \tag{1.12}$$

▼ Discrete loop filter coefficients

$$scale := 33;\ T := \frac{2048}{125e6}$$

$$33$$
$$0.00001638400000 \tag{1.1.1}$$

$$tp := 400e{-}3;\ tz := \frac{tp}{3.5}$$

$$0.400$$
$$0.1142857143 \tag{1.1.2}$$

$$b0 := eval(b0f)$$

$$0.2857289140 \tag{1.1.3}$$

$$b1 := eval(b1f)$$

$$-0.2856879549 \tag{1.1.4}$$

$$a1 := eval(a1f)$$

$$-0.9999590408 \tag{1.1.5}$$

$$tfz := normal\left(\frac{b1 \cdot z^{-1} + b0}{a1 \cdot z^{-1} + 1} \right)$$

$$\frac{-0.2856879549 + 0.2857289140\,z}{-0.9999590408 + z} \tag{1.1.6}$$

$$tzfp := solve(numer(tfz) = 0, z)$$

$$0.9998566505 \tag{1.1.7}$$

$$tpfp := solve(denom(tfz) = 0, z)$$

$$0.9999590408 \tag{1.1.8}$$

$$a1q := QuantizeCoeff(a1, scale);\ CoeffToHex(a1q, 48)$$

$$-8589582755$$
$$FFFE00055E5D \tag{1.1.9}$$

$$b0q := QuantizeCoeff(b0, scale);\ CoeffToHex(b0q, 48)$$

$$2454392682$$
$$924B0F6A \tag{1.1.10}$$

$$b1q := QuantizeCoeff(b1, scale);\ CoeffToHex(b1q, 48)$$

$$-2454040846$$
$$FFFF6DBA4EF2 \tag{1.1.11}$$

$$tfzq := normal\left(\frac{b1q \cdot z^{-1} + b0q}{a1q \cdot z^{-1} + 2^{scale}}\right)$$

$$\frac{2\,(-1227020423 + 1227196341\,z)}{-8589582755 + 8589934592\,z} \tag{1.1.12}$$

$$tzq := solve(numer(tfzq) = 0, z) : evalf\,(\%)$$

$$0.9998566505 \tag{1.1.13}$$

$$tpq := solve(denom(tfzq) = 0, z) : evalf\,(\%)$$

$$0.9999590408 \tag{1.1.14}$$

$$semilogplot\big(20 \cdot log10\big(abs\big(eval(tfzq, z = exp(I \cdot 2 \cdot \pi \cdot f \cdot T))\big)\big), f = 0.001\,..1e3, numpoints = 5000,$$
$$gridlines = true\big)$$
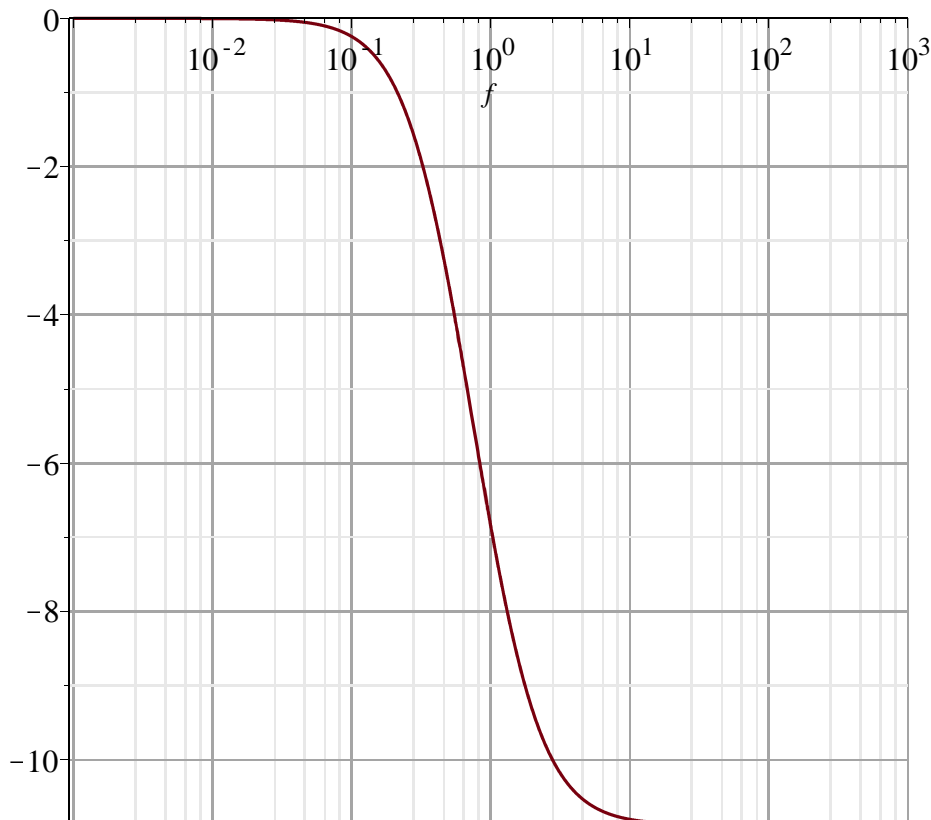
$$semilogplot\left(argument\big(eval(tfzq, z = exp(I \cdot 2 \cdot \pi \cdot f \cdot T))\big) \cdot \frac{180}{\pi}, f = 0.001\,..1e3, numpoints = 5000,\right.$$
$$\left.gridlines = true\right)$$
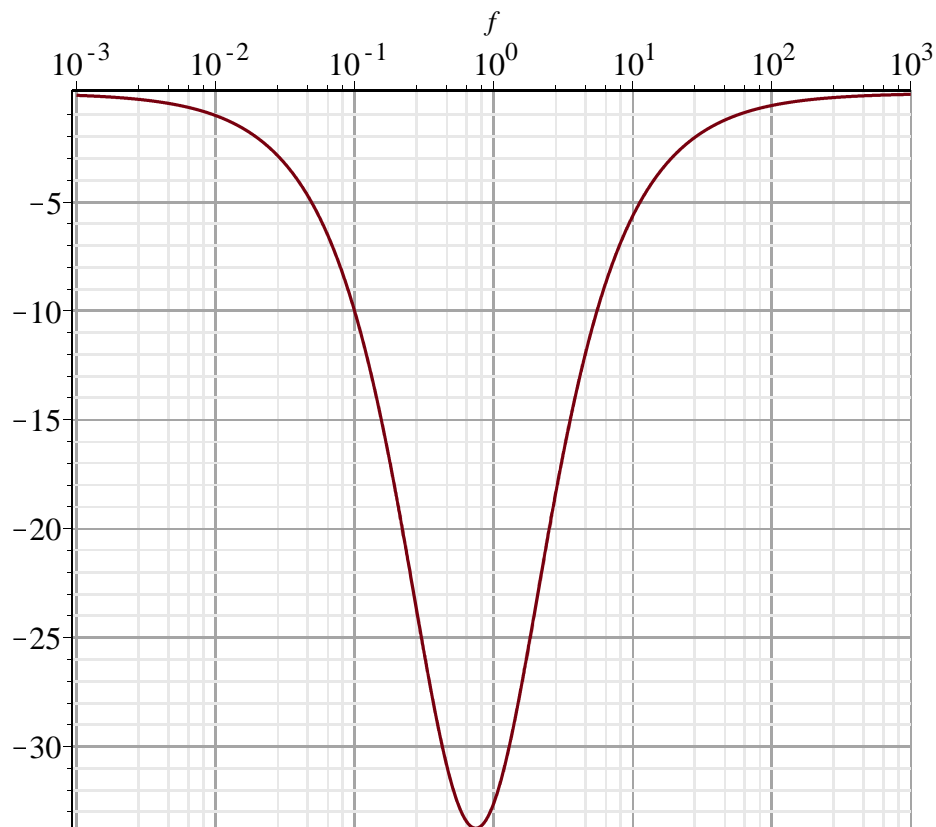
Two pole loop filter

$tf := normal\left(\dfrac{1 + s \cdot tz}{(1 + s \cdot tp1) \cdot (1 + s \cdot tp2)} \right)$

$$\dfrac{s\,tz + 1}{(s\,tp1 + 1)\,(s\,tp2 + 1)} \tag{2.1}$$

$solve(numer(tf) = 0, s)$

$$-\dfrac{1}{tz} \tag{2.2}$$

$solve(denom(tf) = 0, s)$

$$-\dfrac{1}{tp1},\ -\dfrac{1}{tp2} \tag{2.3}$$

$tfzb := normal\left(eval\left(tf, s = \dfrac{2}{T} \cdot \dfrac{1 - z^{-1}}{1 + z^{-1}} \right) \right)$

$$\dfrac{(z + 1)\,T\,(T\,z + 2\,tz\,z + T - 2\,tz)}{(T\,z + 2\,tp2\,z + T - 2\,tp2)\,(T\,z + 2\,tp1\,z + T - 2\,tp1)} \tag{2.4}$$

$tfze := normal\left(eval\left(tf, s = \dfrac{(1 - z^{-1})}{T} \right) \right)$

$$\dfrac{(T\,z + tz\,z - tz)\,T\,z}{(T\,z + tp1\,z - tp1)\,(T\,z + tp2\,z - tp2)} \tag{2.5}$$

$tfznm := collect(numer(tfzb), z)$

$$T(T+2\,tz)\,z^2 + (T(T+2\,tz) + T(T-2\,tz))\,z + T(T-2\,tz) \qquad \textbf{(2.6)}$$

$tfzdn := collect(denom(tfzb), z)$

$$(T+2\,tp2)(T+2\,tp1)\,z^2 + ((T-2\,tp2)(T+2\,tp1) + (T+2\,tp2)(T-2\,tp1))\,z + (T \qquad \textbf{(2.7)}$$
$$-\,2\,tp2)(T-2\,tp1)$$

$b0f := \dfrac{coeff(tfznm, z, 2)}{coeff(tfzdn, z, 2)}$

$$\dfrac{T(T+2\,tz)}{(T+2\,tp2)(T+2\,tp1)} \qquad \textbf{(2.8)}$$

$b1f := \dfrac{coeff(tfznm, z, 1)}{coeff(tfzdn, z, 2)}$

$$\dfrac{T(T+2\,tz) + T(T-2\,tz)}{(T+2\,tp2)(T+2\,tp1)} \qquad \textbf{(2.9)}$$

$b2f := \dfrac{coeff(tfznm, z, 0)}{coeff(tfzdn, z, 2)}$

$$\dfrac{T(T-2\,tz)}{(T+2\,tp2)(T+2\,tp1)} \qquad \textbf{(2.10)}$$

$a0f := \dfrac{coeff(tfzdn, z, 2)}{coeff(tfzdn, z, 2)}$

$$1 \qquad \textbf{(2.11)}$$

$a1f := \dfrac{coeff(tfzdn, z, 1)}{coeff(tfzdn, z, 2)}$

$$\dfrac{(T-2\,tp2)(T+2\,tp1) + (T+2\,tp2)(T-2\,tp1)}{(T+2\,tp2)(T+2\,tp1)} \qquad \textbf{(2.12)}$$

$a2f := \dfrac{coeff(tfzdn, z, 0)}{coeff(tfzdn, z, 2)}$

$$\dfrac{(T-2\,tp2)(T-2\,tp1)}{(T+2\,tp2)(T+2\,tp1)} \qquad \textbf{(2.13)}$$

▼ Discrete loop filter coefficients

$T := \dfrac{512}{125e6}\,;\ scale := 33$

$$0.000004096000000 \qquad$$
$$33 \qquad \textbf{(2.1.1)}$$

$fs := \dfrac{1}{T}$

$$2.441406250\ 10^5 \qquad \textbf{(2.1.2)}$$

$tp1 := 400e-3\,;\ tz := \dfrac{tp1}{3.5}\,;\ tp2 := \dfrac{tz}{50}$

$$0.400 \qquad$$
$$0.1142857143 \qquad$$
$$0.002285714286 \qquad \textbf{(2.1.3)}$$

$b0 := eval(b0f)$

$$0.0002557741032 \qquad \textbf{(2.1.4)}$$

$b1 := eval(b1f)$

$$9.166798166\ 10^{-9} \qquad \textbf{(2.1.5)}$$

$b2 := eval(b2f)$

$$-0.0002557649364 \qquad \textbf{(2.1.6)}$$

$a1 := eval(a1f)$

$$-1.998199364 \tag{2.1.7}$$

$a2 := eval(a2f)$

$$0.9981993826 \tag{2.1.8}$$

$tfz := normal\left(\dfrac{b2 \cdot z^{-2} + b1 \cdot z^{-1} + b0}{a2 \cdot z^{-2} + a1 \cdot z^{-1} + 1} \right)$

$$\dfrac{-0.0002557649364 + 9.166798166 \, 10^{-9} \, z + 0.0002557741032 \, z^2}{0.9981993826 - 1.998199364 \, z + z^2} \tag{2.1.9}$$

$tzfp := solve(numer(tfz) = 0, z)$

$$0.9999641606, \ -1.000000000 \tag{2.1.10}$$

$tpfp := solve(denom(tfz) = 0, z)$

$$0.9999896104, \ 0.9982097536 \tag{2.1.11}$$

$a1q := QuantizeCoeff(a1, scale); \ CoeffToHex(-a1q, 48)$

$$-17164401840$$

$$3FF13FCB0 \tag{2.1.12}$$

$a2q := QuantizeCoeff(a2, scale); \ CoeffToHex(-a2q, 48)$

$$8574467406$$

$$FFFE00EC02B2 \tag{2.1.13}$$

$b0q := QuantizeCoeff(b0, scale); \ CoeffToHex(b0q, 48)$

$$2197083$$

$$21865B \tag{2.1.14}$$

$b1q := QuantizeCoeff(b1, scale); \ CoeffToHex(b1q, 48)$

$$79$$

$$4F \tag{2.1.15}$$

$b2q := QuantizeCoeff(b2, scale); \ CoeffToHex(b2q, 48)$

$$-2197004$$

$$FFFFFFDE79F4 \tag{2.1.16}$$

$tfzq := normal\left(\dfrac{b2q \cdot z^{-2} + b1q \cdot z^{-1} + b0q}{a2q \cdot z^{-2} + a1q \cdot z^{-1} + 2^{scale}} \right)$

$$\frac{1}{2} \, \dfrac{2197083 \, z^2 + 79 \, z - 2197004}{4294967296 \, z^2 - 8582200920 \, z + 4287233703} \tag{2.1.17}$$
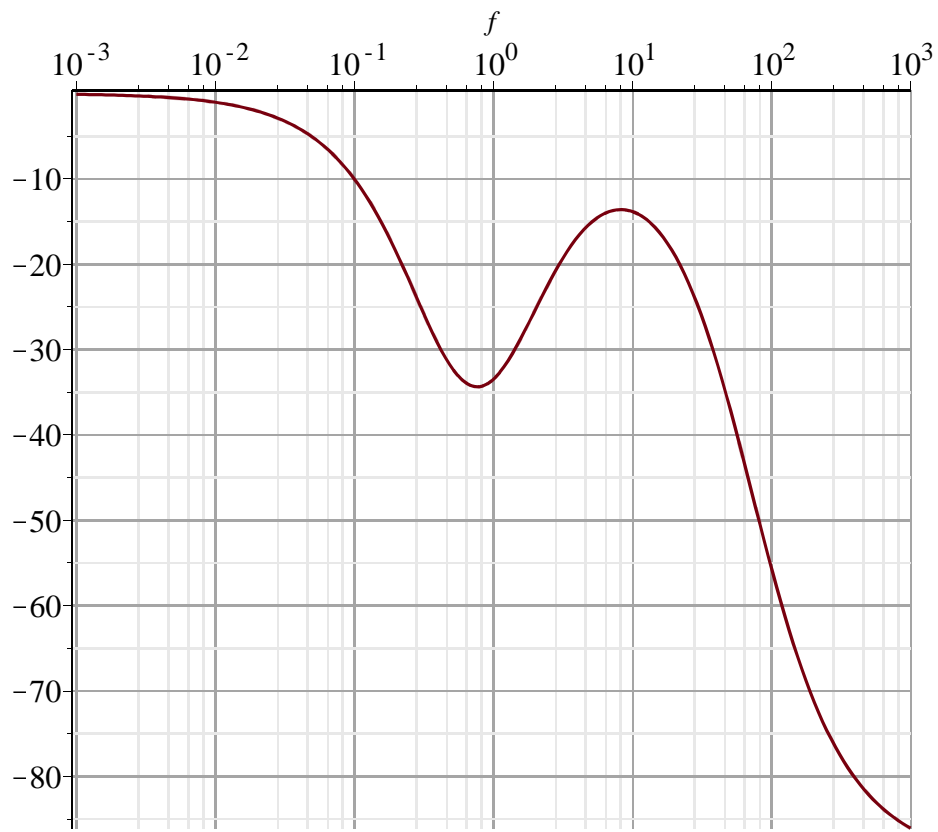
$tzq := solve(numer(tfzq) = 0, z) : evalf(\%)$

$$0.9999640432, \ -1. \tag{2.1.18}$$

$tpq := solve(denom(tfzq) = 0, z) : evalf(\%)$

$$0.9999897263, \ 0.9982096379 \tag{2.1.19}$$

$semilogplot\big(20 \cdot \log10\big(abs\big(eval(tfzq, z = \exp(I \cdot 2 \cdot \pi \cdot f \cdot T)) \big) \big), f = 0.001 \, ..1e3, \ numpoints = 5000,$
$\quad gridlines = true \big)$
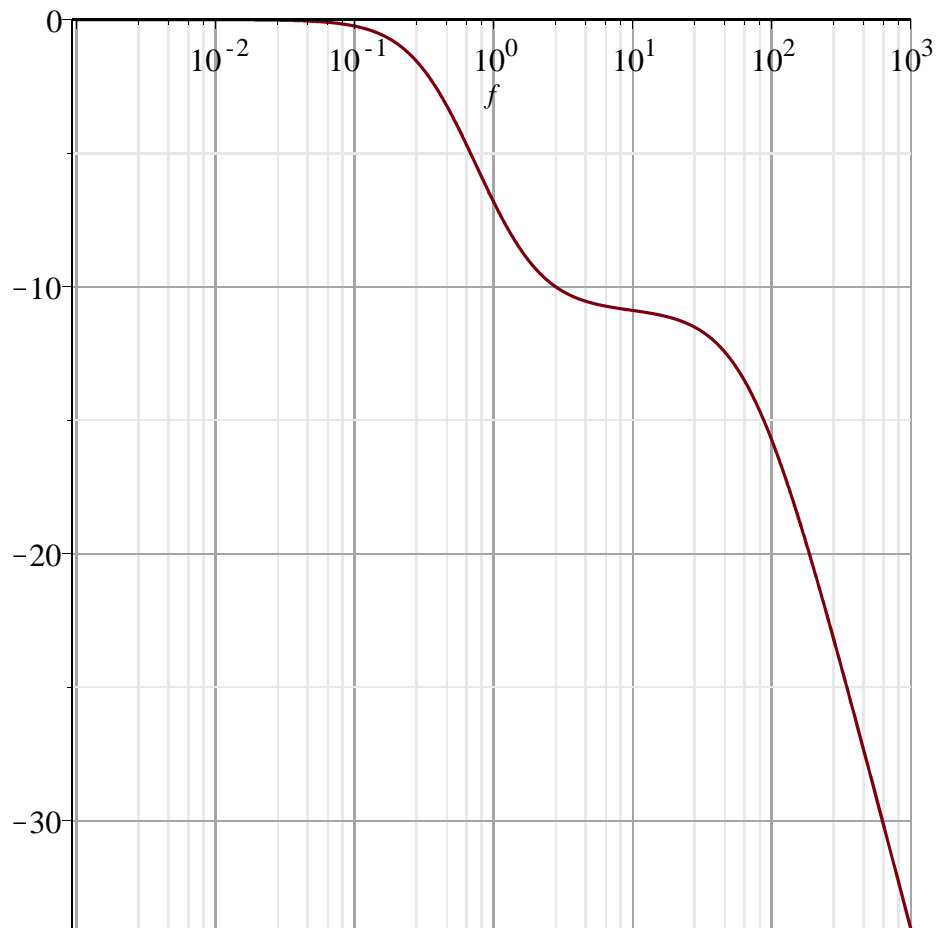
$$semilogplot\left(\text{argument}\left(eval\left(\mathit{tfzq}, z = \exp\left(I \cdot 2 \cdot \pi \cdot f \cdot T \right) \right) \right) \cdot \frac{180}{\pi}, f = 0.001\,..1e3,\ \mathit{gridlines} = \mathit{true} \right)$$

$semilogplot(20 \cdot \log10(\text{abs}(eval(tf, \ s = I \cdot 2 \cdot \pi \cdot f))), f = 0.001 ..1e3, gridlines = true)$
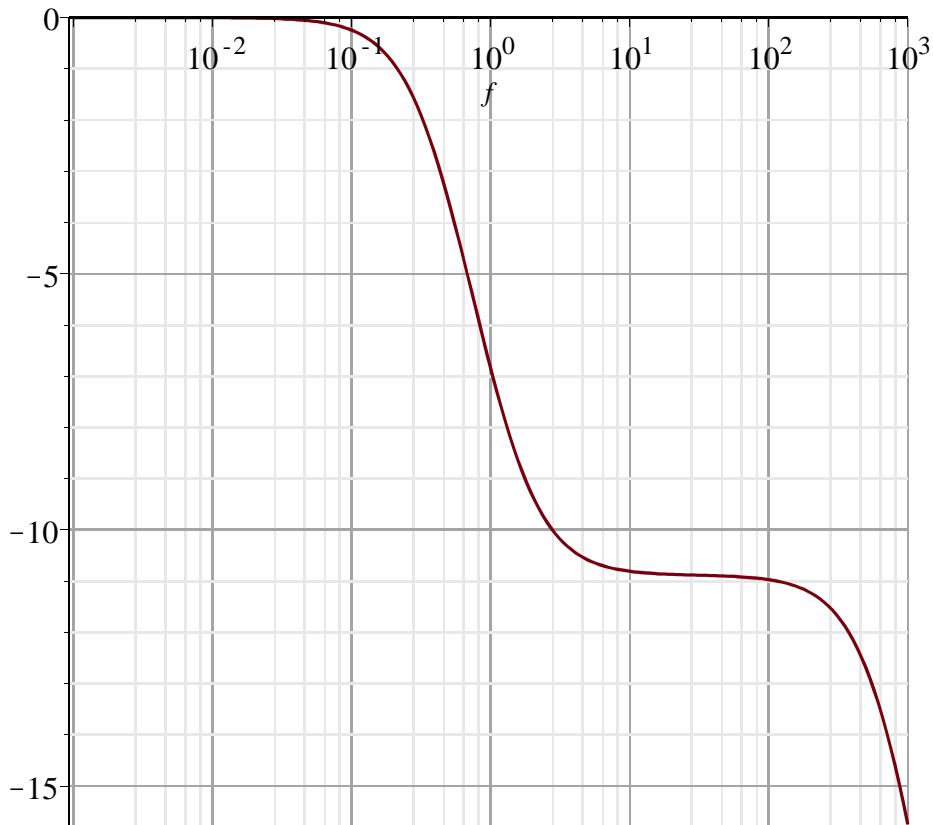
$$eval\left(tfz3, \left\{tz = 1e-3, tp = 25e-3, T = \frac{1}{125e6}\right\}\right)$$

$$\frac{\dfrac{\left(C\,R2 + 8.000000000\,10^{-9}\right) z}{-C\,R1 - C\,R2} - \dfrac{C\,R2}{-C\,R1 - C\,R2}}{\dfrac{\left(C\,R1 + C\,R2 + 8.000000000\,10^{-9}\right) z}{-C\,R1 - C\,R2} + 1} \tag{4}$$

$$18.75000000 \tag{5}$$

$$tfz3 := \frac{\dfrac{(C\,R2 + T)}{-C\,R1 - C\,R2}\,z - \dfrac{C\,R2}{-C\,R1 - C\,R2}}{\dfrac{(C\,R1 + C\,R2 + T)}{-C\,R1 - C\,R2}\,z + 1}$$

$$\frac{\dfrac{(C\,R2 + T)\,z}{-C\,R1 - C\,R2} - \dfrac{C\,R2}{-C\,R1 - C\,R2}}{\dfrac{(C\,R1 + C\,R2 + T)\,z}{-C\,R1 - C\,R2} + 1} \tag{6}$$

$$eval\left(tfz3, \left\{R1 = 25e3, R2 = 1e3, C = 1e-6, T = \frac{1}{125e6}\right\}\right)$$

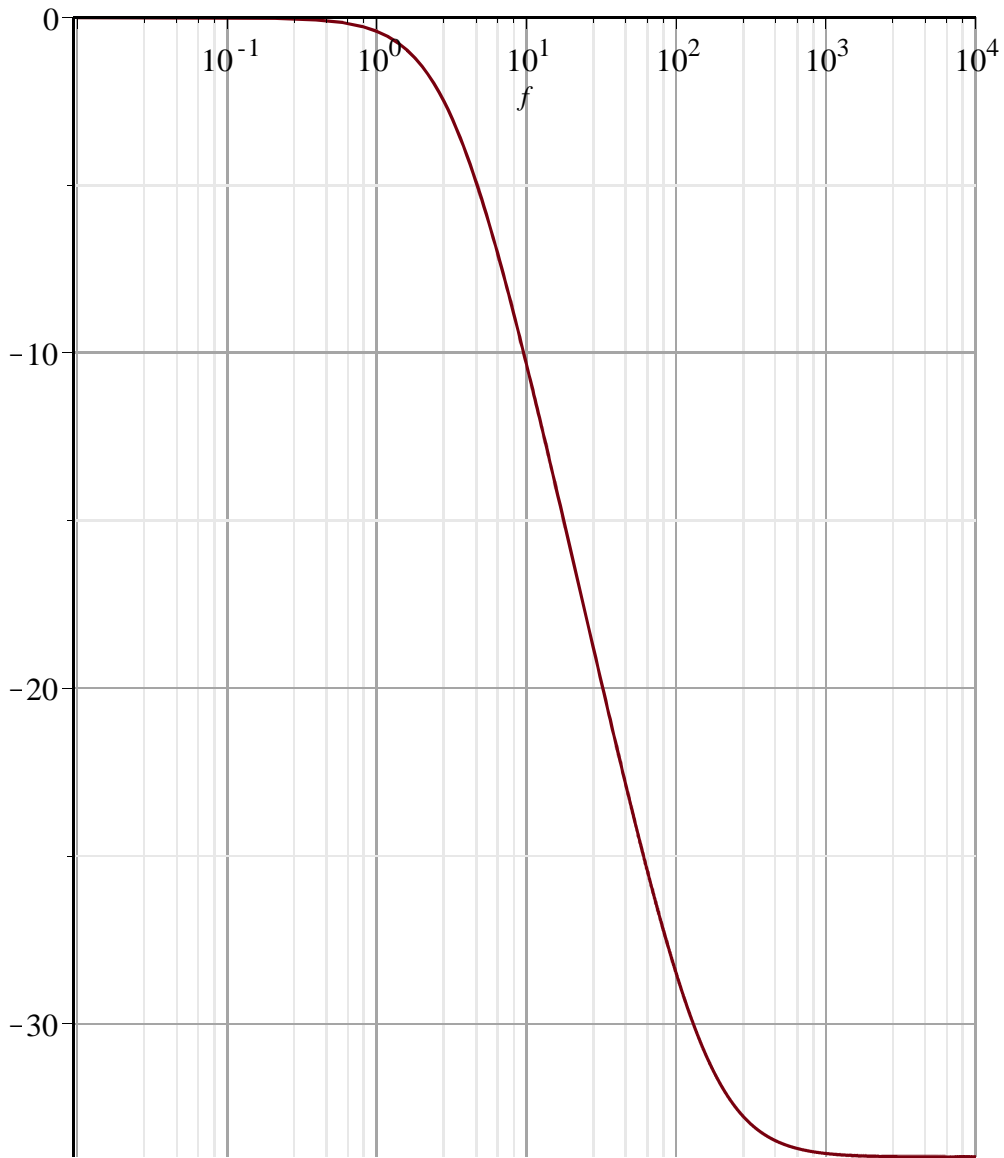$$\frac{-0.03846184615\,z + 0.03846153846}{-1.000000308\,z + 1} \tag{7}$$

$$tfz4 :=$$

$$\frac{\dfrac{(2\,C\,R2 + T)\,z}{-2\,C\,R1 - 2\,C\,R2 + T} + \dfrac{-2\,C\,R2 + T}{-2\,C\,R1 - 2\,C\,R2 + T}}{\dfrac{(2\,C\,R1 + 2\,C\,R2 + T)\,z}{-2\,C\,R1 - 2\,C\,R2 + T} + 1} \tag{8}$$

$eval\left(tfz4,\ \left\{ R1 = 25\mathrm{e}3,\ R2 = 1\mathrm{e}3,\ C = 1\mathrm{e}{-}6,\ T = \dfrac{1}{125\mathrm{e}6} \right\} \right)$

$$\frac{-0.03846169822\,z + 0.03846139053}{-1.000000308\,z + 1} \tag{9}$$

$R1 := 25\mathrm{e}3$

$$25000. \tag{10}$$

$R2 := 1\mathrm{e}3$

$$1000. \tag{11}$$

$C := 1\mathrm{e}{-}6$

$$0.000001 \tag{12}$$

$T := \dfrac{1}{125\mathrm{e}6}$

$$8.000000000\ 10^{-9} \tag{13}$$

$semilogplot\big(20 \cdot \log 10\big(\mathrm{abs}\big(eval\big(eval(tf,\ \{tz = 1\mathrm{e}{-}3,\ tp = 50\mathrm{e}{-}3\}),\ s = I \cdot 2 \cdot \pi \cdot f \big) \big) \big),\ f = 0\,..10\mathrm{e}3,\ numpoints$
$\quad = 50000,\ gridlines = true \big)$

$$-1.810387395\ I,\ 9.865619481\ I \tag{14}$$

tfz

$$\frac{0.001000008000\ z - 0.001}{0.02600000800\ z - 0.026} \tag{15}$$

$$tfz2 := normal\left(\frac{\dfrac{0.001000008000}{-0.048}\ z + \dfrac{-0.001}{-0.048}}{\dfrac{0.04800000800}{-0.048}\ z + 1}\right)$$

$$\frac{0.02083350000\ z - 0.02083333333}{1.000000167\ z - 1.} \tag{16}$$

$b1 := \text{round}\left(-0.02083350000\ \cdot 2^{32}\right)$

$$-89479201 \tag{17}$$

$b0 := \text{round}\left(0.02083333333 \cdot 2^{32}\right)$

$$89478485 \tag{18}$$

$a1 := \text{round}\left(-1.000000167 \cdot 2^{32}\right)$

$$-4294968013 \tag{19}$$

$\dfrac{30}{40.}$

$$0.7500000000 \tag{20}$$

$\dfrac{43.5}{40} \cdot 0.7$

$$0.7612500000 \tag{21}$$

$\dfrac{45}{125\text{e}6} \cdot 2^{32}$

$$1546.188226 \tag{22}$$

$evalf\left(\dfrac{10}{2 \cdot \pi}\right)$

$$1.591549430 \tag{23}$$