FET IQ Demodulator

```
Needs["Controls`LinearControl`"]
$TextStyle = {FontFamily → "Helvetica", FontSize → 13};
plotopt = PlotStyle → {{Thickness[0.007], RGBColor[1, 0, 0]},
                {Thickness[0.007], RGBColor[0, 0, 1]},
                {Thickness[0.007], RGBColor[0.1, 0.7, 0.2]},
                {Thickness[0.007], RGBColor[0.5, 0.5, 0.2]}};
textoptsmall = {TextStyle → {FontFamily → "Helvetica", FontSize → 11}};
```

$$\text{par}[\text{r1\_}, \text{r2\_}] := \frac{1}{\frac{1}{\text{r1}} + \frac{1}{\text{r2}}}$$

$$\text{par}[\text{r1\_}, \text{r2\_}, \text{r3\_}] := \frac{1}{\frac{1}{\text{r1}} + \frac{1}{\text{r2}} + \frac{1}{\text{r3}}}$$

Parameters

C6: fast capacitor to ground at mixer output
C3: large capacitor to ground at mixer output
R11: series resistance into mixer
RDS: mixer on resistance
R6: series resistor into OpAmp
L1: series inductor into OpAmp
L1R: series resistance of L1 coil
R2: feedback resistor of OpAmp
C1: feedback capacitor of OpAmp

Normal

```
prm = {C6 → 1*^-9, C3 → 47*^-9, R11 → 182, RDS → 8,
  R6 → 10, L1 → 2.2*^-6, L1R → 2.8, R2 → 1000, C1 → 1*^-9, s → 2 π ⅈ f}
```

$$\left\{C6 \to \frac{1}{1\,000\,000\,000}, C3 \to \frac{47}{1\,000\,000\,000}, R11 \to 180, RDS \to 8, R6 \to 10, L1 \to 2.2\times 10^{-6}, L1R \to 2.8, R2 \to 1000, C1 \to \frac{1}{1\,000\,000\,000}, s \to 2\,i\,f\,\pi\right\}$$

Wide bandwidth

```
prmW = {C6 → 1*^-9, C3 → 4.7*^-9, R11 → 180, RDS → 8, R6 → 10,
   L1 → 0.22*^-6, L1R → 0.84, R2 → 1000,  C1 → 100*^-12, s → 2 π ⅈ f}
```

$\left\{C6 \to \frac{1}{1\,000\,000\,000}, C3 \to 4.7\times10^{-9}, R11 \to 180, RDS \to 8, R6 \to 10, L1 \to 2.2\times10^{-7}, L1R \to 0.84, R2 \to 1000, C1 \to \frac{1}{10\,000\,000\,000}, s \to 2\,i\,f\,\pi\right\}$

Ultra-wide bandwidth

```
prmUW = {C6 → 1*^-9, C3 → 2.2*^-9, R11 → 180, RDS → 8,
   R6 → 10, L1 → 0.22*^-6, L1R → 0.84, R2 → 1000,  C1 → 10*^-12, s → 2 π ⅈ f}
```

$\left\{C6 \to \frac{1}{1\,000\,000\,000}, C3 \to 2.2\times10^{-9}, R11 \to 180, RDS \to 8, R6 \to 10, L1 \to 2.2\times10^{-7}, L1R \to 0.84, R2 \to 1000, C1 \to \frac{1}{100\,000\,000\,000}, s \to 2\,i\,f\,\pi\right\}$

Formulae

v1: Voltage at the IF point

i1: current into virtual ground

v2: voltage at OpAmp output

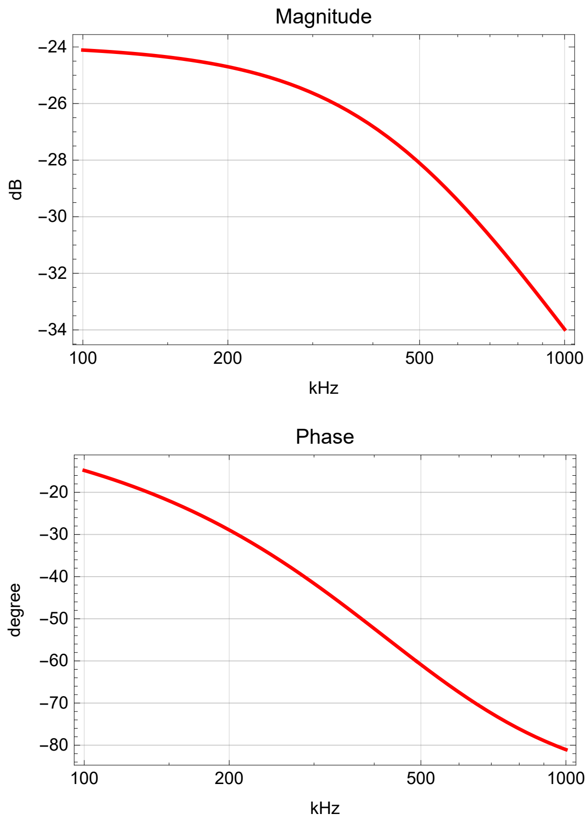
```
z2 = s L1 + R6  + L1R;
z1 = par[1/(s C6), 1/(s C3), z2] // Together
v1 = z1/(R11 + RDS + z1);
i1 = v1 / z2;
v2 = i1 par[R2, 1/(s C1)];
```

$(L1R + R6 + L1\,s) \,/\, \left(1 + C3\,L1R\,s + C6\,L1R\,s + C3\,R6\,s + C6\,R6\,s + C3\,L1\,s^2 + C6\,L1\,s^2\right)$

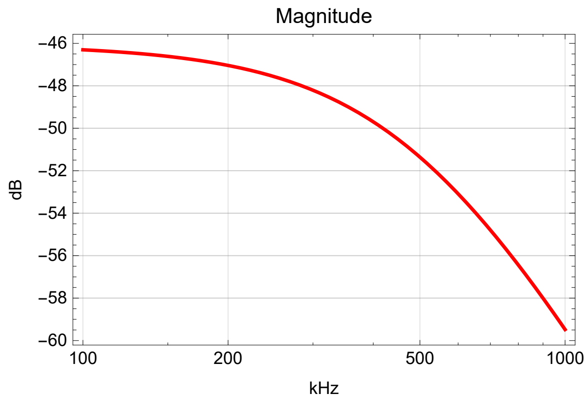
Plots

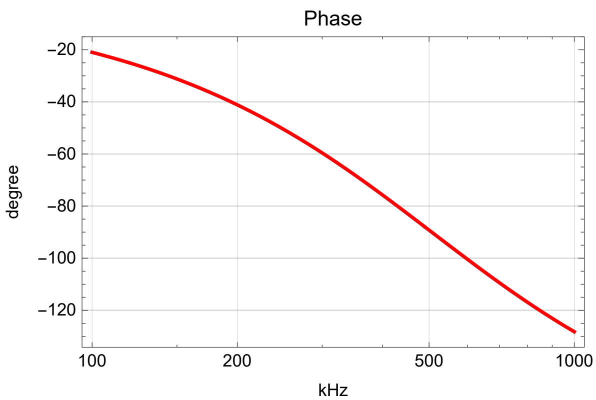
Normal

```
BodePlotEx[v1 /. prm /. f → 1*^3 ff, {ff, 100, 1000}, plotopt, XAxisLabel → "kHz"]
```

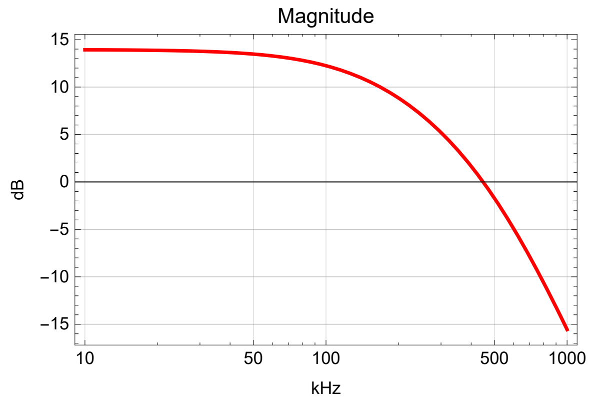


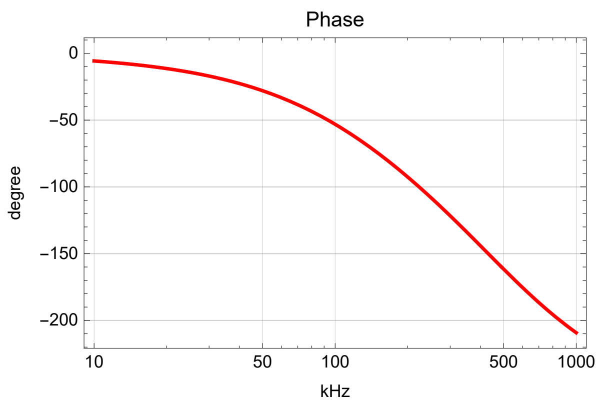
```
BodePlotEx[i1 /. prm /. f → 1*^3 ff, {ff, 100, 1000}, plotopt, XAxisLabel → "kHz"]
```





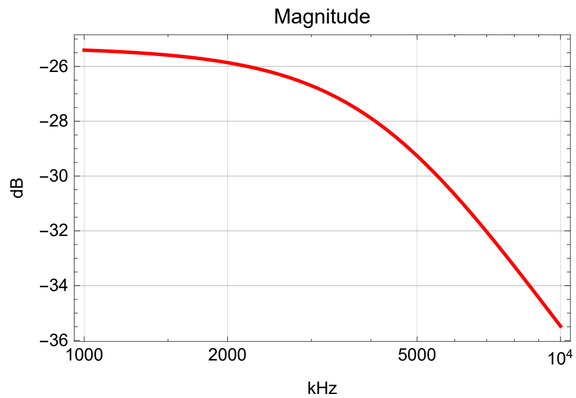
```
BodePlotEx[v2 /. prm /. f → 1*^3 ff, {ff, 10, 1000}, plotopt, XAxisLabel → "kHz"]
```

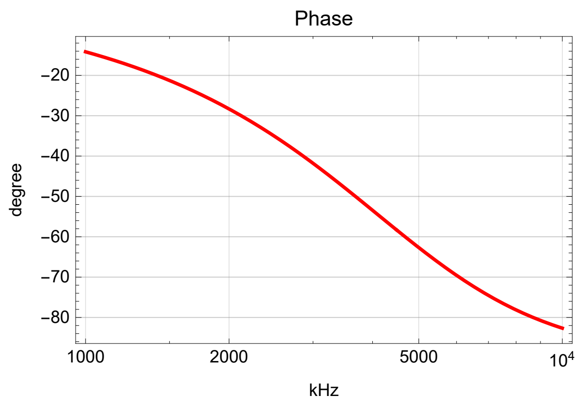




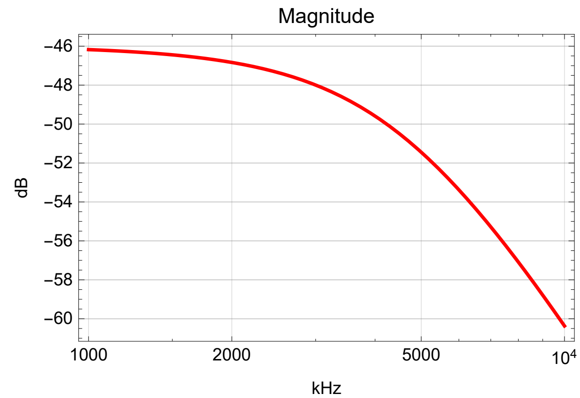
Wide bandwidth

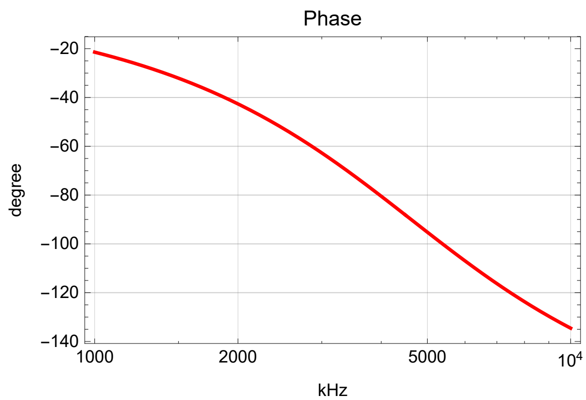
```
BodePlotEx[v1 /. prmW /. f → 1*^3 ff, {ff, 1000, 10 000}, plotopt, XAxisLabel → "kHz"]
```



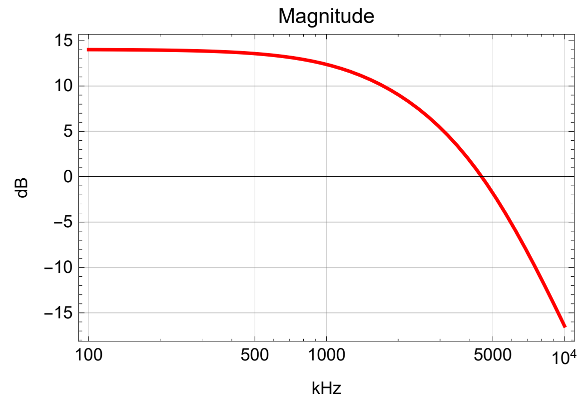


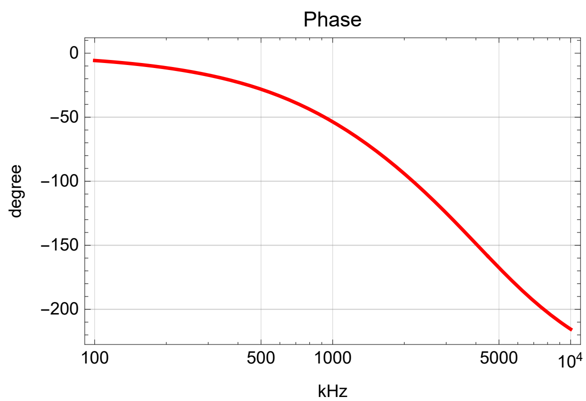
```
BodePlotEx[i1 /. prmW /. f → 1*^3 ff, {ff, 1000, 10 000}, plotopt, XAxisLabel → "kHz"]
```





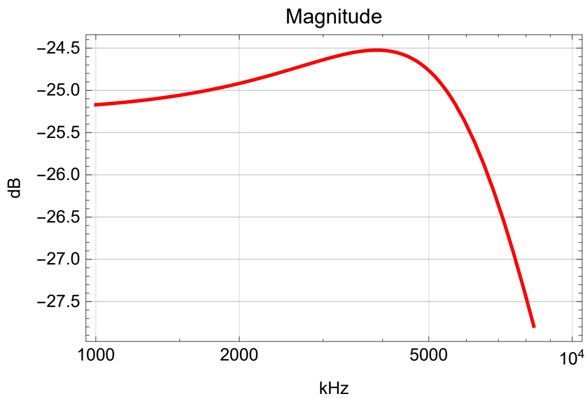
```
BodePlotEx[v2 /. prmW /. f → 1*^3 ff, {ff, 100, 10 000}, plotopt, XAxisLabel → "kHz"]
```

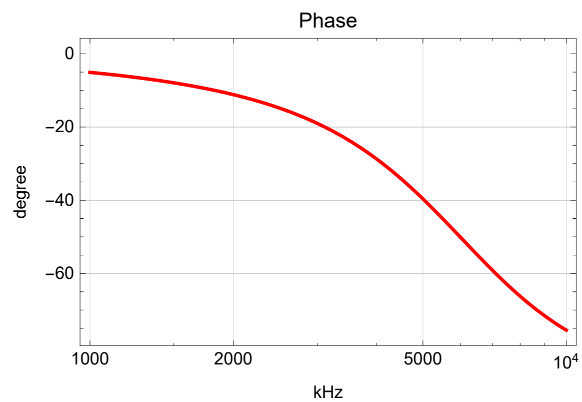




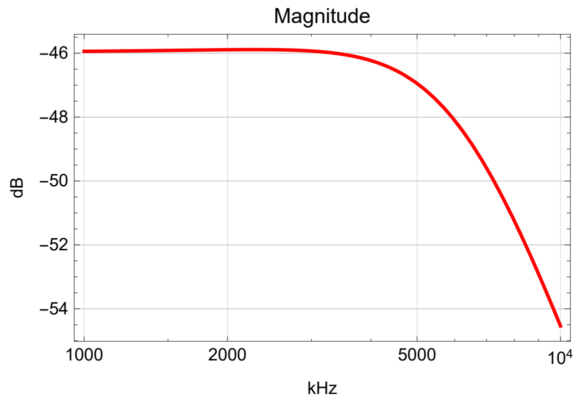
Ultra-wide bandwidth

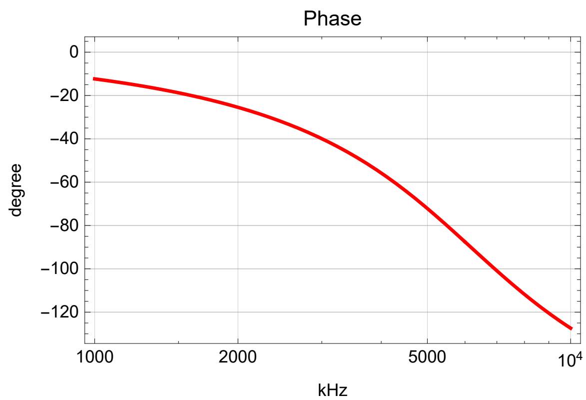
```
BodePlotEx[v1 /. prmUW /. f → 1*^3 ff, {ff, 1000, 10 000}, plotopt, XAxisLabel → "kHz"]
```



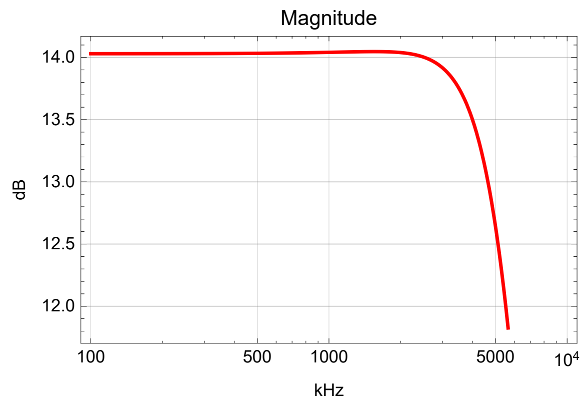


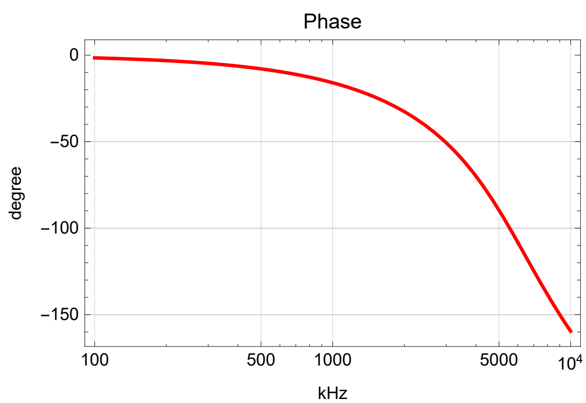
```
BodePlotEx[i1 /. prmUW /. f → 1*^3 ff, {ff, 1000, 10 000}, plotopt, XAxisLabel → "kHz"]
```





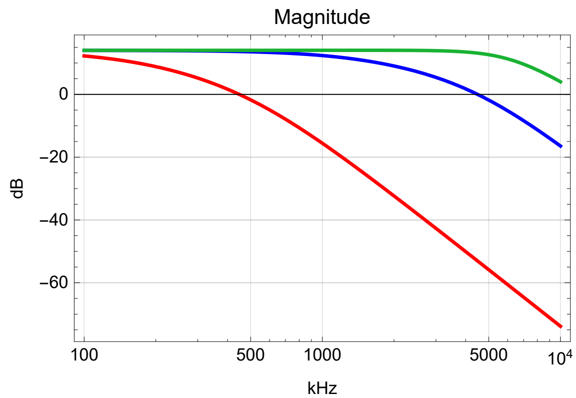
```
BodePlotEx[v2 /. prmUW /. f → 1*^3 ff, {ff, 100, 10 000}, plotopt, XAxisLabel → "kHz"]
```

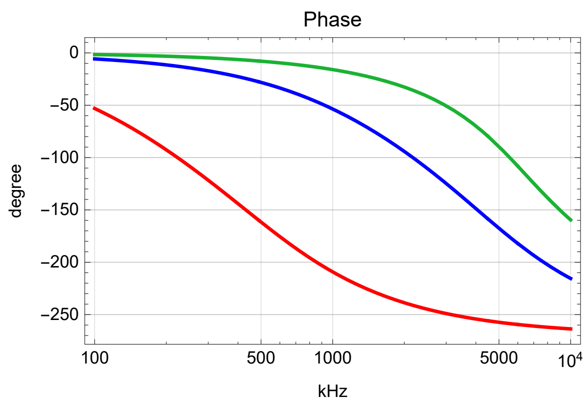




Comparison

```
BodePlotEx[{v2 /. prm /. f → 1*^3 ff, v2 /. prmW /. f → 1*^3 ff, v2 /. prmUW /. f → 1*^3 ff},
 {ff, 100, 10 000}, plotopt, XAxisLabel → "kHz"]
```





Values (Normal)

DC gain

```
dcgain = Abs[v2] /. prm /. {f → 0.}
4.98008
```

Poles

```
Collect[Denominator[v2], s]
f /. Solve[% == 0 /. s → -2 π f, f] /. prm // N
Abs[%]
Abs[%%] / (2 Re[%%])
```

$$\left(\frac{1}{R2} + C1\,s\right)\left(1 + C3\,L1R\,s + C6\,L1R\,s + C3\,R6\,s + C6\,R6\,s + C3\,L1\,s^2 + C6\,L1\,s^2\right)\left(R11 + RDS + \left(L1R + R6 + L1\,s\right) \Big/ \left(1 + C3\,L1R\,s + C6\,L1R\,s + C3\,R6\,s + C6\,R6\,s + C3\,L1\,s^2 + C6\,L1\,s^2\right)\right)$$

{159155., 471815. + 183283. i, 471815. - 183283. i}

{159155., 506164., 506164.}

{0.5, 0.536401, 0.536401}

Bandwidth

```
f /. FindRoot[Abs[v2] == dcgain/√2 /. prm, {f, 0.5*^5, 5*^5}]
```

141001.

Phase at 10 kHz

```
Arg[v2]/Degree /. prm /. {f → 10*^3}
```

-5.70543

Phase at 100 kHz

```
Arg[v2]/Degree /. prm /. {f → 100*^3}
```

-53.1125

LC circuit resonant frequency and Q

```
LCpoles = Solve[z2 / z1 == 0, s];
LComega = Sqrt[Times @@ (s /. LCpoles)] // Simplify;
LCQ = LComega / (Plus @@ (-s /. LCpoles)) // Simplify;
Sqrt[LCQ^2] // Simplify // PowerExpand;

LComega / (2 π) /. prm
LCQ /. prm
```

489 765.

0.528909

Values (Wide bandwidth)

DC gain

```
dcgain = Abs[v2] /. prmW /. {f → 0.}
```

5.02917

Poles

```
Collect[Denominator[v2], s]
f /. Solve[% == 0 /. s → -2 π f, f] /. prmW // N
Abs[%]
Abs[%%] / (2 Re[%%])
```

$\left(\frac{1}{R2} + C1\ s\right)\ (1 + C3\ L1R\ s + C6\ L1R\ s + C3\ R6\ s + C6\ R6\ s + C3\ L1\ s^2 + C6\ L1\ s^2)$
$\ (R11 + RDS + (L1R + R6 + L1\ s) / (1 + C3\ L1R\ s + C6\ L1R\ s + C3\ R6\ s + C6\ R6\ s + C3\ L1\ s^2 + C6\ L1\ s^2))$

$\{1.59155 \times 10^6,\ 3.99526 \times 10^6 + 2.32426 \times 10^6\ i,\ 3.99526 \times 10^6 - 2.32426 \times 10^6\ i\}$

$\{1.59155 \times 10^6,\ 4.62215 \times 10^6,\ 4.62215 \times 10^6\}$

{0.5, 0.578455, 0.578455}

Bandwidth

$$f\ /.\ \text{FindRoot}\left[\text{Abs}[v2] == \frac{\text{dcgain}}{\sqrt{2}}\ /.\ \text{prmW},\ \{f, 0.5*^5, 5*^5\}\right]$$

1.43335×10^6

Phase at 10 kHz

$$\frac{\text{Arg}[v2]}{\text{Degree}}\ /.\ \text{prmW}\ /.\ \{f \to 10*^3\}$$

-0.574289

Phase at 100 kHz

$$\frac{\text{Arg}[v2]}{\text{Degree}}\ /.\ \text{prmW}\ /.\ \{f \to 100*^3\}$$

-5.73821

Phase at 1 MHz

$$\frac{\text{Arg}[v2]}{\text{Degree}}\ /.\ \text{prmW}\ /.\ \{f \to 1*^6\}$$

-53.5659

LC circuit resonant frequency and Q

$$\text{LCpoles} = \text{Solve}\left[z2 \,/\, z1 == 0,\ s\right];$$

$$\text{LComega} = \sqrt{\text{Times}\ @@\ (s\ /.\ \text{LCpoles})}\ //\ \text{Simplify};$$

$$\text{LCQ} = \frac{\text{LComega}}{\text{Plus}\ @@\ (-s\ /.\ \text{LCpoles})}\ //\ \text{Simplify};$$

$$\sqrt{\text{LCQ}^2}\ //\ \text{Simplify}\ //\ \text{PowerExpand};$$

$$\frac{\text{LComega}}{2\,\pi}\ /.\ \text{prmW}$$

$$\text{LCQ}\ /.\ \text{prmW}$$

4.4944×10^6

0.573119

Values (Ultra-wide bandwidth)

DC gain

```
dcgain = Abs[v2] /. prmUW /. {f → 0.}
```

5.02917

Poles

```
Collect[Denominator[v2], s]
f /. Solve[% == 0 /. s → -2 π f, f] /. prmUW // N
Abs[%]
Abs[%%] / (2 Re[%%])
```

$$\left(\frac{1}{R2} + C1\ s\right)\left(1 + C3\ L1R\ s + C6\ L1R\ s + C3\ R6\ s + C6\ R6\ s + C3\ L1\ s^2 + C6\ L1\ s^2\right)$$
$$\left(R11 + RDS + \frac{L1R + R6 + L1\ s}{1 + C3\ L1R\ s + C6\ L1R\ s + C3\ R6\ s + C6\ R6\ s + C3\ L1\ s^2 + C6\ L1\ s^2}\right)$$

$\{1.59155 \times 10^7,\ 4.05328 \times 10^6 + 4.65039 \times 10^6\ i,\ 4.05328 \times 10^6 - 4.65039 \times 10^6\ i\}$

$\{1.59155 \times 10^7,\ 6.16889 \times 10^6,\ 6.16889 \times 10^6\}$

{0.5, 0.760975, 0.760975}

Bandwidth

```
f /. FindRoot[Abs[v2] == dcgain/√2 /. prmUW, {f, 0.5*^6, 5*^6}]
```

6.1876×10^6

Phase at 10 kHz

```
Arg[v2]/Degree /. prmUW /. {f → 10*^3}
```

-0.158052

Phase at 100 kHz

```
Arg[v2]/Degree /. prmUW /. {f → 100*^3}
```

-1.58065

Phase at 1 MHz

```
Arg[v2]/Degree /. prmUW /. {f → 1*^6}
```

−15.9354

LC circuit resonant frequency and Q

```
LCpoles = Solve[z2 / z1 == 0, s];
LComega = Sqrt[Times @@ (s /. LCpoles)] // Simplify;
LCQ = LComega / (Plus @@ (-s /. LCpoles)) // Simplify;
Sqrt[LCQ^2] // Simplify // PowerExpand;
```

```
LComega/(2 π) /. prmUW
LCQ /. prmW
```

5.99838×10^{6}

0.573119