

PULSES AND WAVEFORMS

Francesco Mezzanino

*The subscript "gd" is the acronym of "Global Data.xmcd"
The subscript "fs" is the acronym of "Fourier series.xmcd"
The subscript "sl" is the acronym of "Signal List.xmcd"
The subscript "dp" is the acronym of "Dirac Pulse - formulas.xmcd"*

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FILES REFERENCES

- ▶ Reference:E:\Pulses And Waveforms\Pulses and Waveforms formulae.xmcd(R)
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- ▶ Reference:E:\Pulses And Waveforms\staircase pulse data.xmcd(R)
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- ▶ Reference:E:\Pulses And Waveforms\staircase 4 pulse data.xmcd(R)
- ▶ Reference:E:\Pulses And Waveforms\sawtooth pulse data.xmcd(R)
- ▶ Reference:E:\Pulses And Waveforms\FM data.xmcd(R)
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INTRODUCTION

This worksheet deal with deterministic pulses and signals only.

It is a collection of some common (and not), signals used in electronics.

To simplify the realization of this file (this worksheet) and to make more agile and immediate viewing of signal's graphics, the data, for some signal, are defined in other worksheets as listed in the references just above this introduction. (for example: Staircase, Pulse train, FM and PM signal, etc).

Hence, to change the data, open the relative file and modify them. Save and close both files (relative file data and this one) to store the data variations done, than reopen Pulses and Waveforms.

Units: Mrads and Grads stand for $10^6 \cdot \text{rad}$ and $10^9 \cdot \text{rad}$

PULSES

Pulses

-1) Dirac Pulse Approximation

Dirac pulse definition: $\Delta(t) = \begin{cases} \infty & \text{if } t = 0.0 \\ 0.0 & \text{otherwise} \end{cases}$

Some text of electrical engineering, use the symbol: $u_0(t) = \begin{cases} \infty & \text{if } t = 0.0 \\ 0.0 & \text{otherwise} \end{cases}$

$$\int_{-\infty}^{\infty} \Delta(t) dt = 1 \qquad \int_{-\infty}^{\infty} u_0(t) dt = 1$$

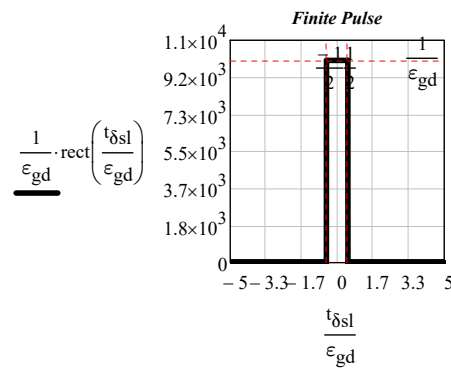
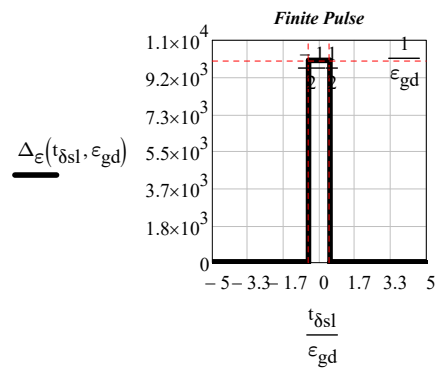
Let's now approximate the Dirac Pulse in a way that it can be drawn, namely define a time interval as small as desired, for example:

approximation. $\Delta_\epsilon(t, \epsilon_{gd}) = \begin{cases} \frac{1}{\epsilon_{gd}} & \text{if } \frac{-\epsilon_{gd}}{2} \leq t \leq \frac{\epsilon_{gd}}{2} \\ 0 & \text{otherwise} \end{cases}$

Dirac Pulse property: $\int_{-\infty}^{\infty} \Delta_\epsilon(t, \epsilon_{gd}) dt = \int_{-\frac{\epsilon_{gd}}{2}}^{\frac{\epsilon_{gd}}{2}} \Delta_\epsilon(t, \epsilon_{gd}) dt = 1$

$$\lim_{\epsilon \rightarrow 0} \int_{-\frac{\epsilon_{gd}}{2}}^{\frac{\epsilon_{gd}}{2}} \Delta_\epsilon(t, \epsilon_{gd}) dt = 1 \qquad \int_{-\infty}^{\infty} \lim_{\epsilon \rightarrow 0} \Delta_\epsilon(t, \epsilon_{gd}) dt = 0$$

$$\epsilon_{gd} = 1 \times 10^5 \frac{1}{s} \cdot ns \qquad t_{\delta sl} := -5 \cdot \epsilon_{gd}, -5 \cdot \epsilon_{gd} + \frac{10 \cdot \epsilon_{gd}}{2000} \dots 5 \cdot \epsilon_{gd}$$



Pulses

-2) Voltage step

Some text in electrical engineering indicate the unitary step with the symbol: $u_{-1}(t) = \int_{-\infty}^t u_0(\xi) d\xi = \Phi(t)$,

therefore: $u_0(t) = \frac{d}{dt} u_{-1}(t)$.

Other definition are $\Phi(t) = \lim_{\epsilon_{gd} \rightarrow 0} \int_{-\infty}^t \frac{1}{\epsilon_{gd}} \cdot \Pi\left(\frac{\xi}{\epsilon_{gd}}\right) d\xi = \int_{-\infty}^t u_0(\xi) d\xi = \int_{-\infty}^t \Delta(\xi) d\xi$

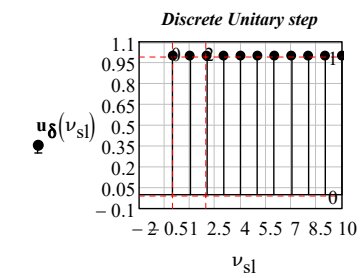
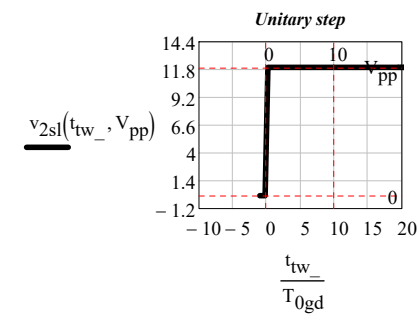
Voltage step $V_{stpsl}(t_{sl}, V_{pp}) = V_{pp} \cdot \Phi(t_{sl})$

Discrete time Unitary step (Unitary pulse: $\delta(\nu, k)$):

$$v_{2sl}(t_{sl}) = \frac{V_{stpsl}(t_{sl}, V_{pp})}{V} \qquad u_{\delta}(\nu) = \begin{cases} \sum_{k=0}^{\nu} \delta(\nu, k) & \text{if } \nu \geq 0 \\ 0 & \text{otherwise} \end{cases}$$

T_{0gd} and V_{pp} are defined in "general data.xmcd "

$$V_{pp} = 1.2 \times 10^4 \cdot mV \qquad t_{tw-} := -1 \cdot T_{0gd}, -1 \cdot T_{0gd} + \frac{201 \cdot T_{0gd}}{500} \dots 200 \cdot T_{0gd} \qquad \nu_{sl} := 0 \dots 20 \qquad T_{0gd} = 1 \times 10^{-3} s$$



Pulses

-3) Ramp with slope V_1/T

Some text of electrical engineering indicate the ramp function, use the symbol: $u_2(t_{sl}) := t_{sl} \cdot \Phi(t_{sl})$

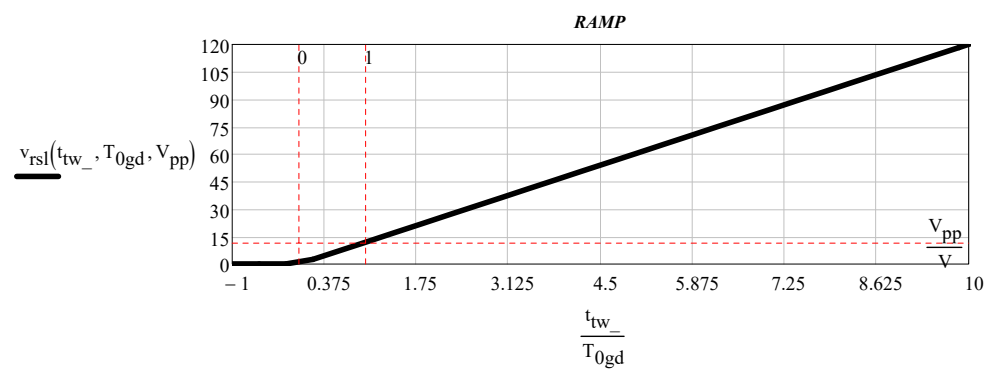
T_{0gd} and V_{pp} are defined in "general data.xmcd"

$$u_2(t_{sl}) = t_{sl} \cdot \Phi(t_{sl}) = \int_{-\infty}^{t_{sl}} \Phi(\xi) d\xi$$

Voltage ramp:

$$T_{0gd} := T_{0gd} \quad V_{pp} := V_{pp} \quad u_2(t_{sl}) = \frac{V_{pp}}{T_{0gd}} \int_0^{t_{sl}} \Phi(\tau_{tw}) d\tau_{tw}$$

$$v_{rsl}(t_{sl}, T_{0gd}, V_{pp}) = \frac{V_{pp}}{T_{0gd}} \cdot \frac{t_{sl} \cdot \Phi(t_{sl})}{V}$$



Pulses

-4) Voltage Pulse

Description of the Function's parameters:

$$V_4(t_{sl}, \tau_{\delta sl}, \tau_{ptd_}, V_{pp}) = \text{Adimensional_amplitude} \cdot \text{rect1}(\text{time}, \text{risingedge width})$$

Data file "pulse train data.xmcd"

$$\text{Pulse width: } \tau_{ptd_} = 250 \cdot \mu\text{s}, \quad T_{0gd} = 1 \times 10^3 \cdot \mu\text{s},$$

$$\text{Amplitude: } V_{pp} = 12 \cdot \text{volt}$$

$$\text{Pulse displacement from the origin: } \xi_{tws1} := \xi_{ptd_}, \quad \tau_{ptd_} = \tau_{ptd_} \cdot (1 - \xi_{tws1}) + \xi_{tws1} \tau_{ptd_}$$

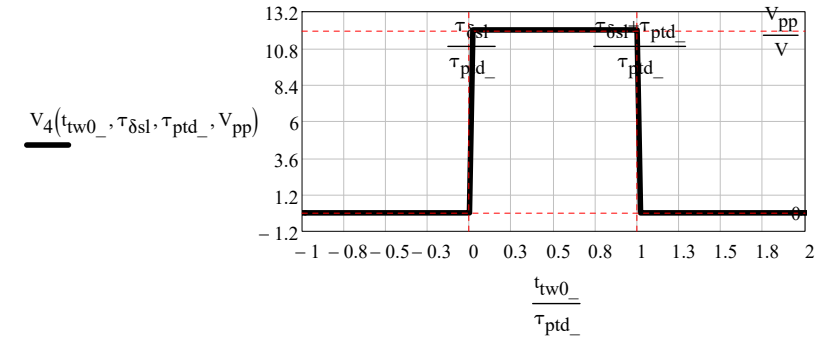
$$\text{Time delay from the origin: } \tau_{\delta sl} := -\tau_{ptd_} \cdot (1 - \xi_{tws1}), \quad \text{risingedge} = \tau_{\delta sl}, \quad \text{width} = \tau_{ptd_}$$

Generic pulse definition defined in "Fourier Series.xmcd": $\text{rect1}(t_{sl}, \text{risingedge}, \text{width})$

$$\tau_{\delta sl} = 0 \cdot \mu\text{s} \quad V_4(t_{sl}, \tau_{\delta sl}, \tau_{ptd_}, V_{pp}) = \frac{V_{pp}}{V} \cdot \text{rect1}(t_{sl}, \tau_{\delta sl}, \tau_{ptd_})$$

$$t_{tw0_} := -2 \cdot \tau_{ptd_}, -2 \cdot \tau_{ptd_} + \frac{102 \cdot \tau_{ptd_}}{5000} \dots 100 \cdot \tau_{ptd_}$$

Single Pulse



Pulses

-5 Doublet Voltage Pulse

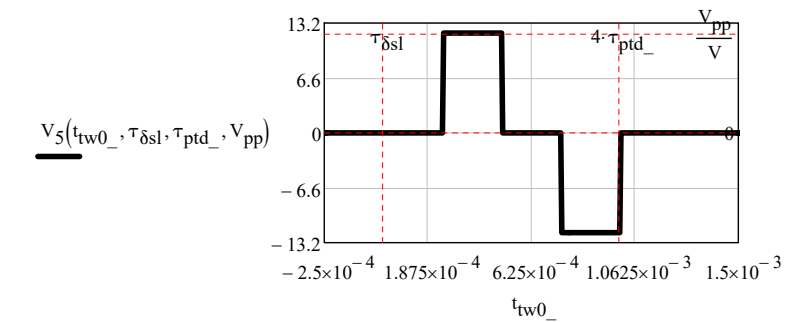
Description of the Function's parameters: $V_4(t_{sl}, \text{risingedge width}, \text{pulse_amplitude})$

$V_5(t_{sl}, \text{risingedge width}, \text{pulse_amplitude})$

Data file "pulse train data.xmcd"

$$\tau_{ptd_} = 250 \cdot \mu\text{s} \quad V_4(t_{sl}, \tau_{\delta sl}, \tau_{ptd_}, V_{pp}) = \frac{V_{pp}}{V} \cdot \text{rect1}(t_{sl}, \tau_{\delta sl}, \tau_{ptd_})$$

$$V_5(t_{sl}, \tau_{\delta sl}, \tau_{ptd_}, V_{pp}) = V_4(t_{sl} - \tau_{ptd_}, \tau_{\delta sl}, \tau_{ptd_}, V_{pp}) - V_4(t_{sl} - 3 \cdot \tau_{ptd_}, \tau_{\delta sl}, \tau_{ptd_}, V_{pp})$$



Pulses

-6 Staircase 1 Voltage Pulse

Data file "staircase pulse data.xmcd"

$$k_{\text{stplength}} = 300$$

Step Amplitude (arbitrary choice): $V_{\text{stcstp0}} = 2.4 \cdot \text{mV}$

Number of steps: $m1_{\text{steps}} = 8$

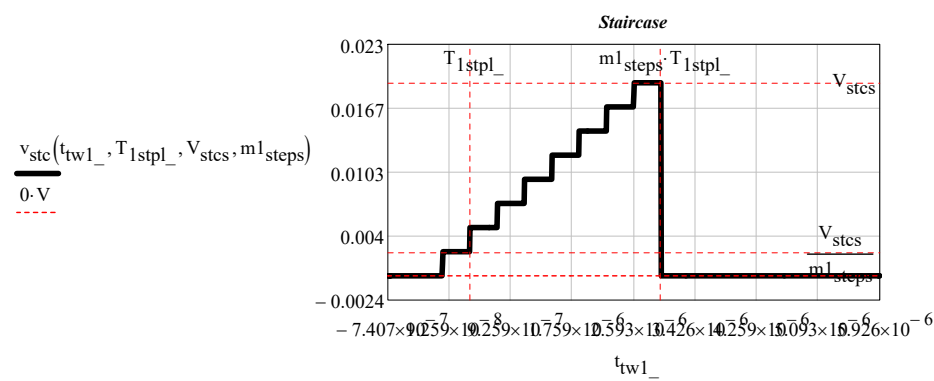
Signal amplitude: $V_{\text{stcs}} = 19.2 \cdot \text{mV}$

Step length: $T_{1\text{stpl}} = 0.37 \cdot \mu\text{s}$

Description of the Function's parameters: $v_{\text{stc}}(t_{\text{sl}}, \text{step_length}, \text{signal_amplitude}, \text{number_of_step})$

Test signal:

$$v_{\text{stc}}(t_{\text{sl}}, T_{1\text{stpl}}, V_{\text{stcs}}, m1_{\text{steps}}) = \frac{V_{\text{stcs}}}{m1_{\text{steps}}} \left[\sum_{k=0}^{m1_{\text{steps}}-1} (\Phi(t_{\text{sl}} - k \cdot T_{1\text{stpl}})) - m1_{\text{steps}} \cdot \Phi(t_{\text{sl}} - m1_{\text{steps}} \cdot T_{1\text{stpl}}) \right]$$

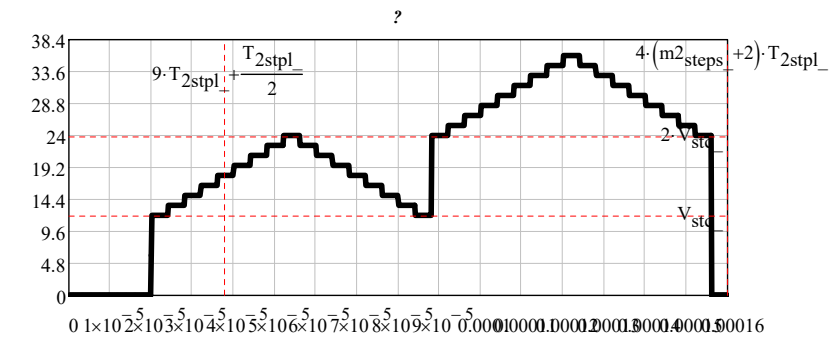
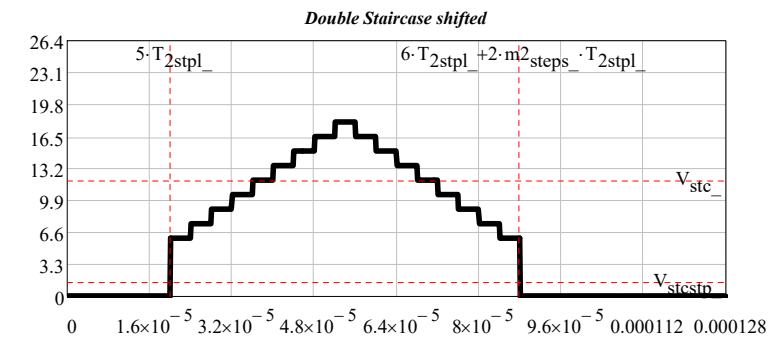
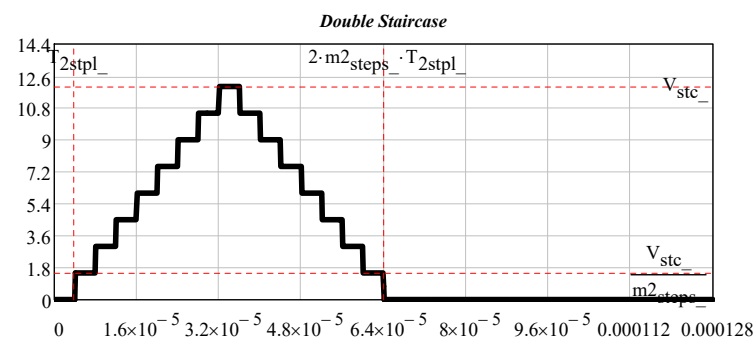


Pulses

-7 Staircase 2 Voltage Pulse

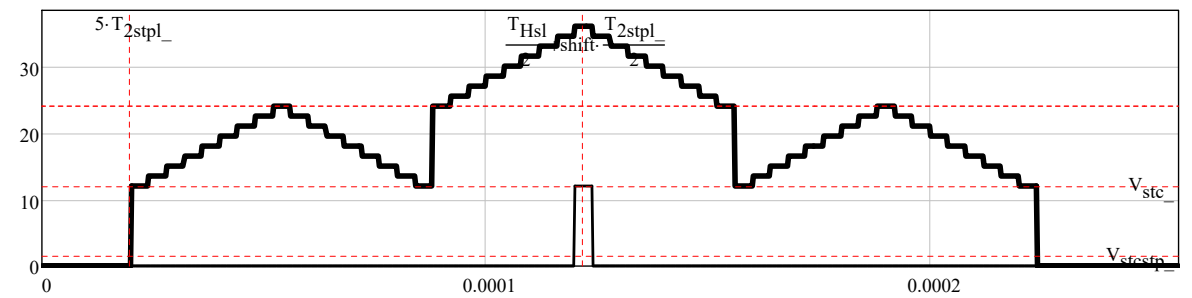
Data file "staircase 2 pulse data.xmcd"

shift := 5



$$T_{\text{Hsl}} := (6 \cdot m2_{\text{steps}} + \text{shift} + 3) \cdot T_{2\text{stpl}}$$

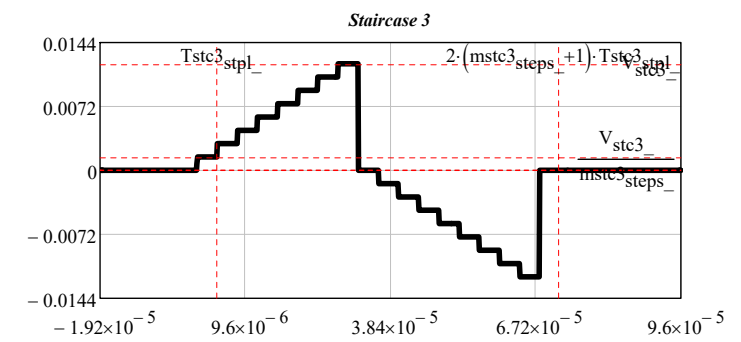
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Pulses

-8 Staircase 3 Voltage Pulse

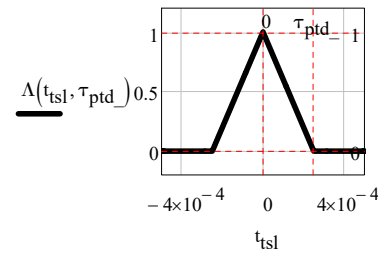
Data file "staircase 3 pulse data.xmcd"



Pulses

-9 Triangular Voltage Pulse

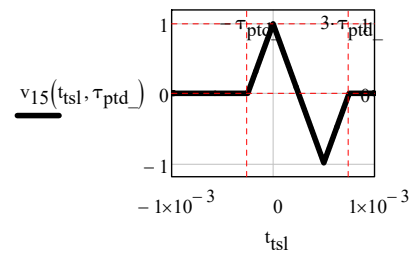
Data file "general data.xmcd"



Pulses

-10 Bipolar Triangular Voltage Pulse

Data file "general data.xmcd"

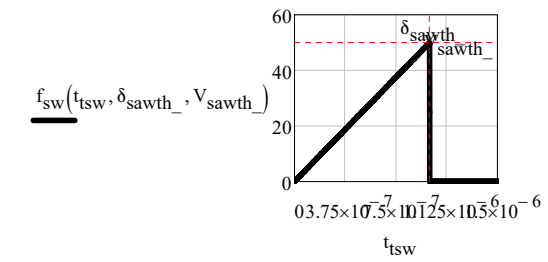


Pulses

-11 Sawtooth Voltage Pulse with positive slope

Data file "sawtooth pulse data.xmcd"

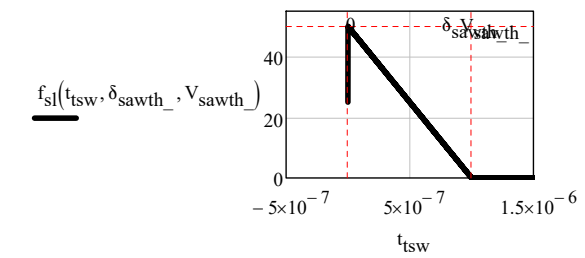
$$t_{\text{tsw}} := -\delta_{\text{sawth_}} \cdot 0, -\delta_{\text{sawth_}} \cdot 0 + \frac{5 \cdot \delta_{\text{sawth_}} + \delta_{\text{sawth_}} \cdot 0}{10000} .. 5 \cdot \delta_{\text{sawth_}}$$



Pulses

-12 Sawtooth Voltage Pulse with negative slope

Data file "sawtooth pulse data.xmcd"



Pulses

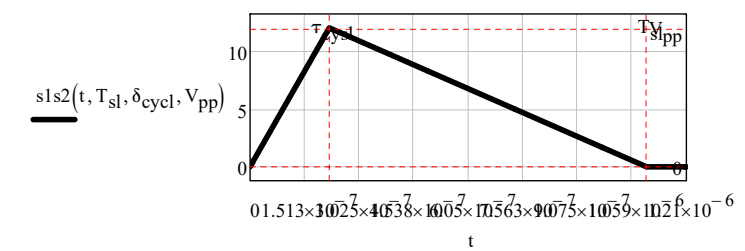
-13 Bipolar Single Sawtooth with adjustable rising and falling edges Pulse Train

Data file "sawtooth pulse data.xmcd"

$$V_{\text{pp}} = 12 \text{ V}$$

$$T_{\text{sl}} := 1.1 \cdot \mu\text{s} \quad \omega_{0\text{sl}} := \frac{2 \cdot \pi}{T_{\text{sl}}} \quad \omega_{0\text{sl}} = 5.712 \cdot \frac{\text{Mrads}}{\text{sec}} \quad \delta_{\text{cycl}} = 0.2$$

$$\tau_{\text{cycl}} := \delta_{\text{cycl}} \cdot T_{\text{sl}}$$



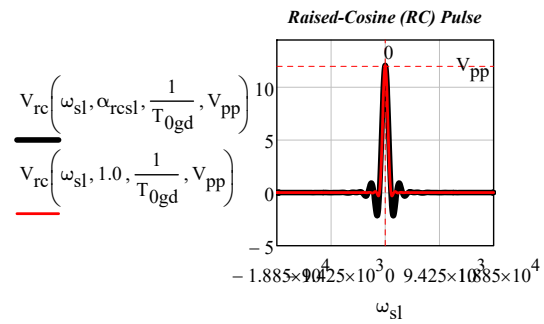
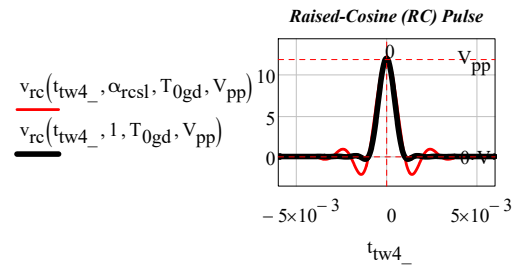
Pulses

-14 Raised-Cosine (RC) Pulse

α is called the excess bandwidth factor. The bandwidth of this pulse is $Bw_{rc} = \frac{1 + \alpha_{rcsl}}{2 \cdot T_{rcsl}}$

sinc is a Mathcad function, it returns the value of $\sin(z)/z$, with correct behavior in the limit as z approaches 0.

$$\alpha_{rcsl} := 0.3 \quad T_{rcsl} := T_{0gd} \quad Bw_{rcsl} := \frac{1 + \alpha_{rcsl}}{2 \cdot T_{0gd}}$$



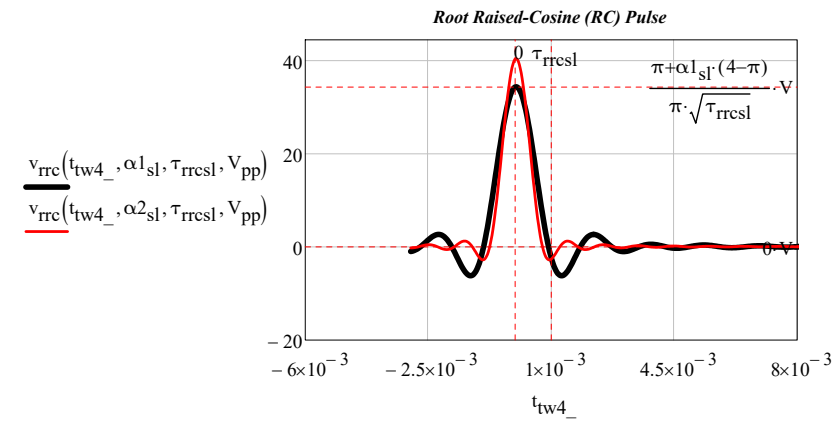
Pulses

-15 Root Raised-Cosine (RC) Pulse

$$\tau_{rrcsl} := T_{0gd} \quad \alpha_{1sl} := 0.3 \quad \alpha_{2sl} := 1.0 \quad \alpha_{rrcsl} := \alpha_{1sl} \quad T_{rrcsl} := 6 \cdot T_{0gd} \quad T_{rrcsl} = 6 \times 10^{-3} \text{ s}$$

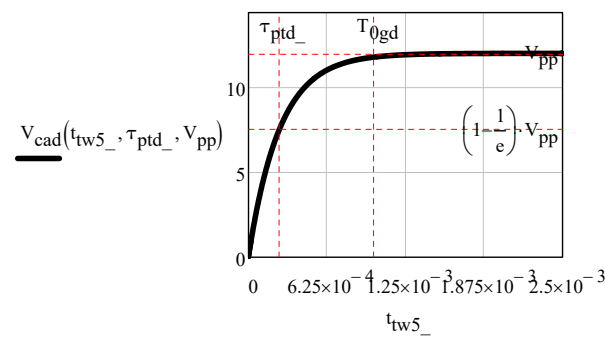
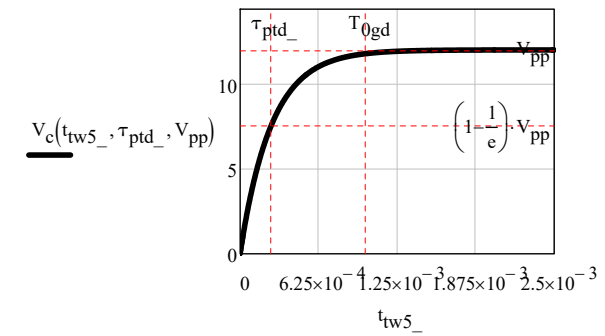
$$\tau_{rrcsl} = 1 \times 10^{-3} \text{ s}$$

$$t_{tw4_} := -T_{0gd} \cdot 3, -T_{0gd} \cdot 3 + \frac{10 \cdot T_{0gd} + T_{0gd} \cdot 3}{500} \dots 10 \cdot T_{0gd}$$



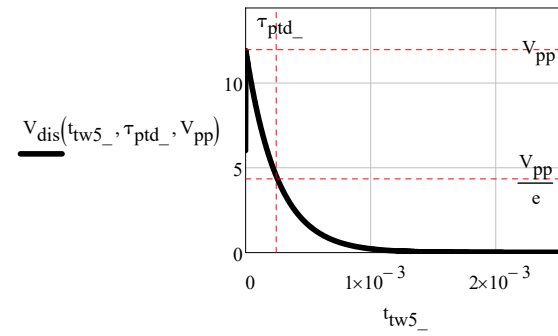
Pulses

-16 Voltage Pulse Exponentially Rising



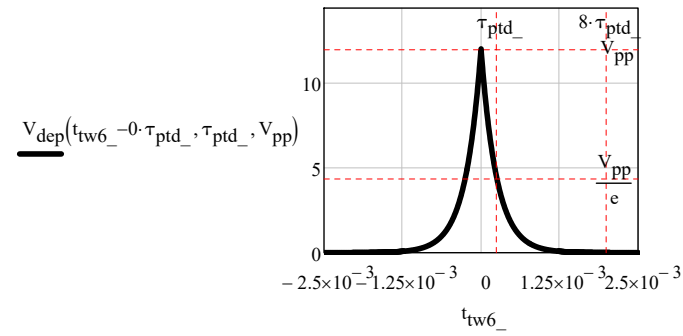
Pulses

-17 Voltage Pulse Exponentially Decaying



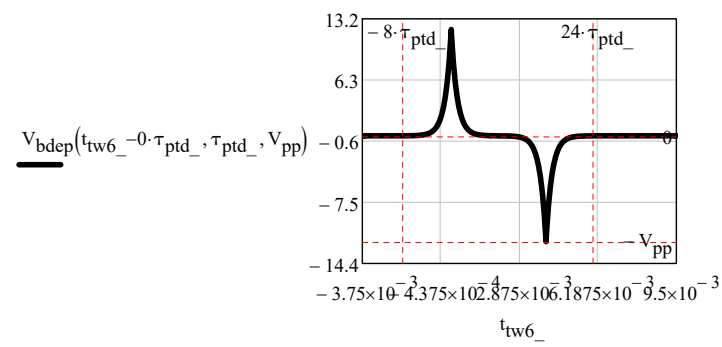
Pulses

-18 Double Exponential Pulse



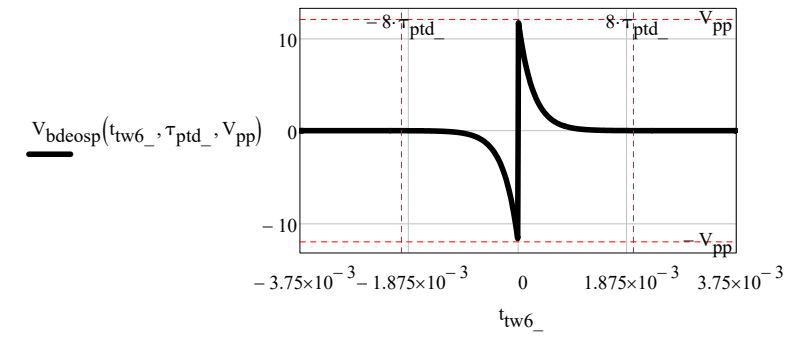
Pulses

-19 Bipolar Double Exponential Pulse



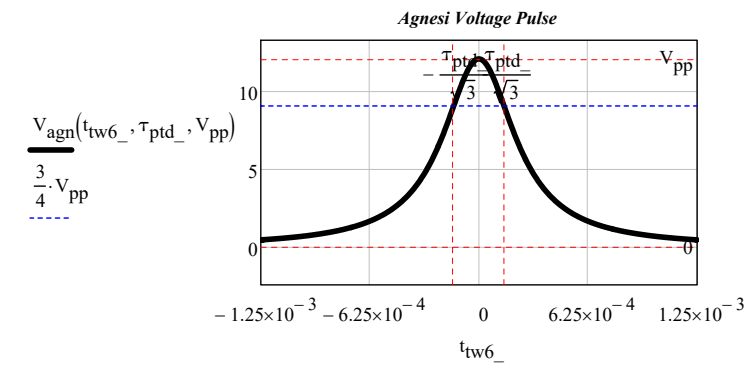
Pulses

-20 Bipolar Double Exponential Odd symmetric Pulse



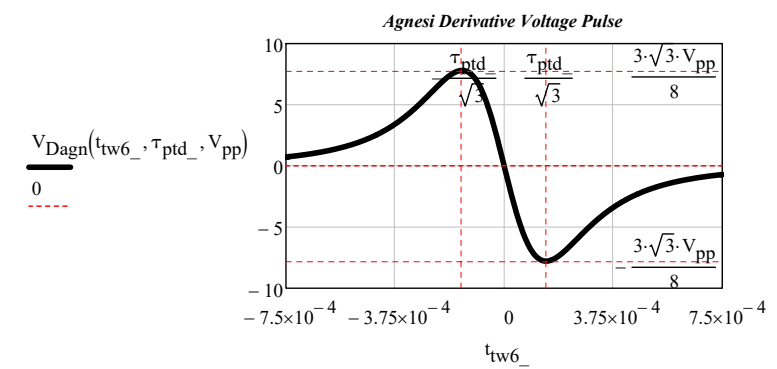
Pulses

-21 Agnesi Profile Voltage Pulse



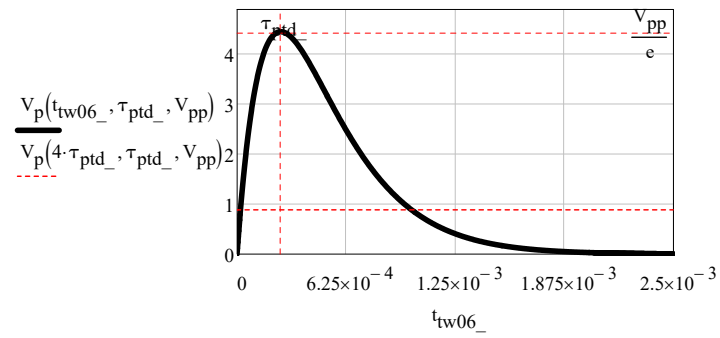
Pulses

-22 Agnesi Derivative Voltage Pulse



Pulses

- 23 Poisson Profile Voltage Pulse



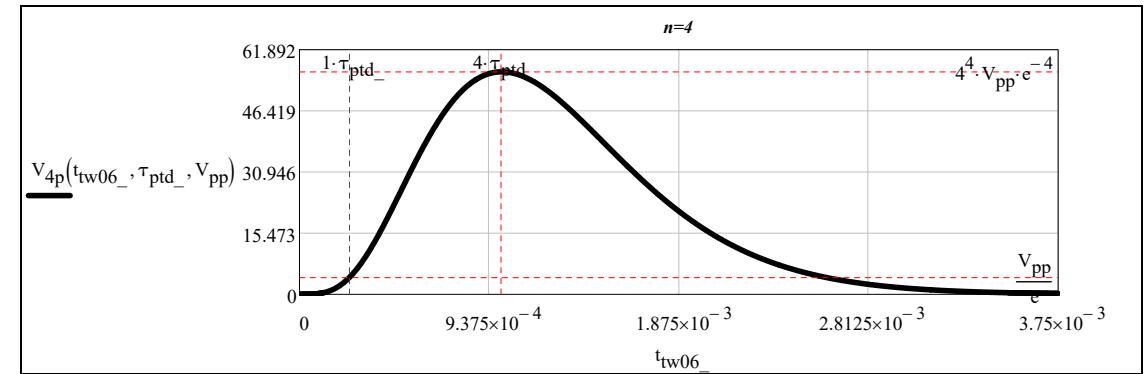
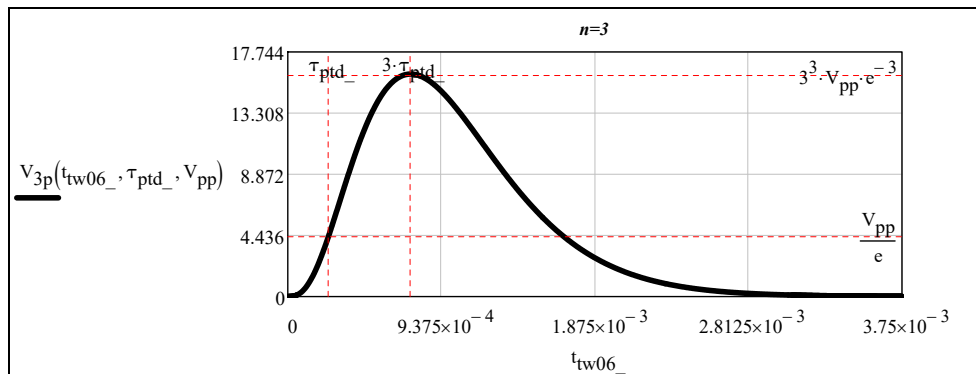
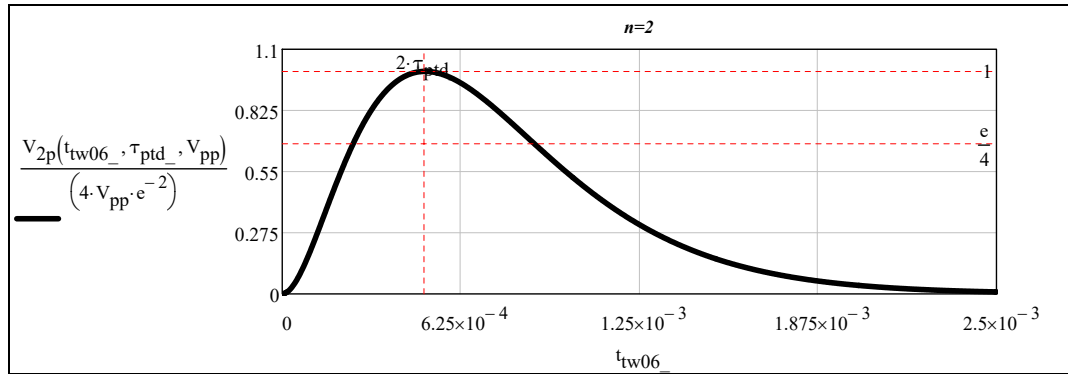
Pulses

- 24 nth Poisson Profile Voltage Pulse

$$n_{sl} := 2$$

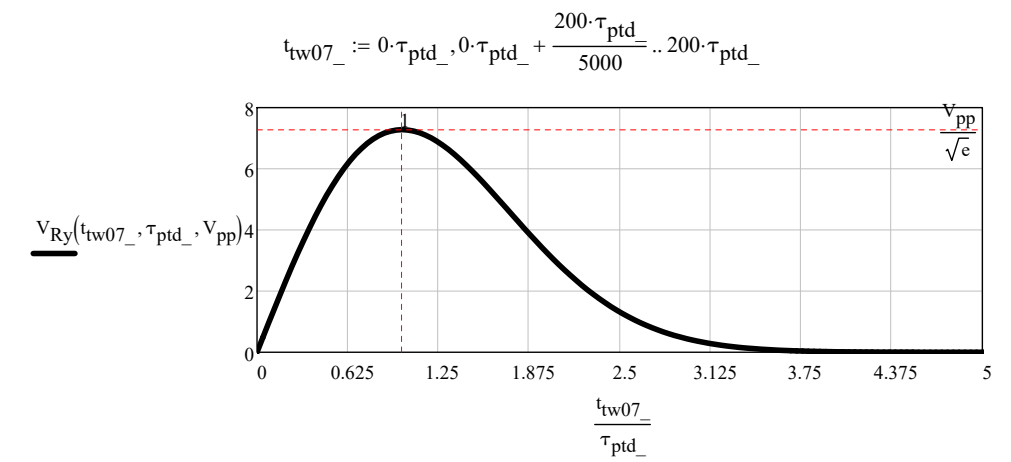
$$\max_{y_{sl}} := V_{pp} \cdot e^{-n_{sl}} \cdot n_{sl}^{n_{sl}} \quad \max_{y_{sl}} = 6.496 \cdot V \quad \max_{x_{sl}} := n_{sl} \cdot \tau_{ptd_}$$

$$t_{tw_} := 0 \cdot \tau_{ptd_} + 0 \cdot \tau_{ptd_} + \frac{200 \cdot \tau_{ptd_}}{500} \dots 200 \cdot \tau_{ptd_}$$



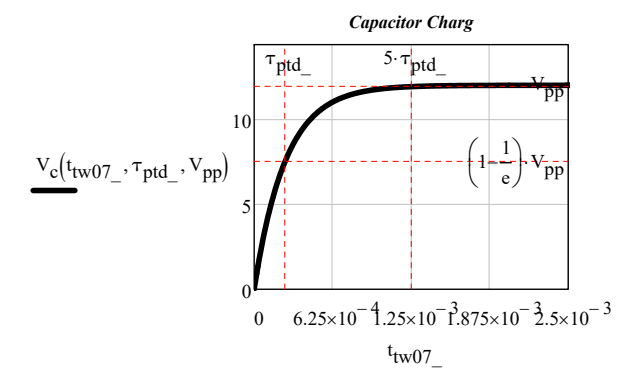
Pulses

- 25 Rayleigh Profile Voltage Pulse

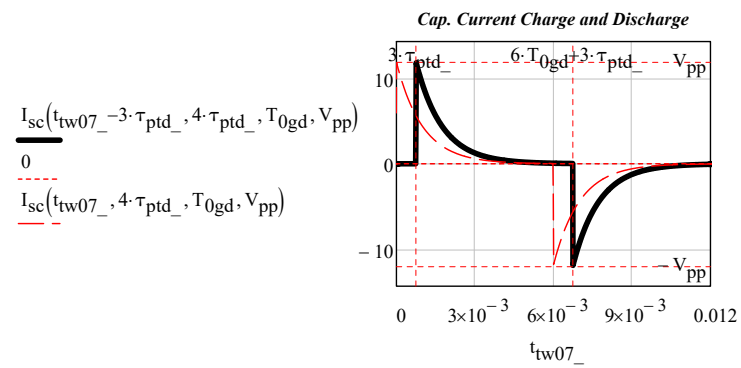
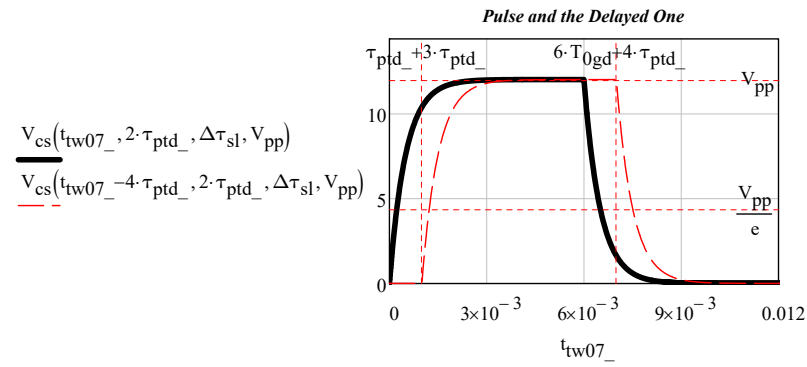
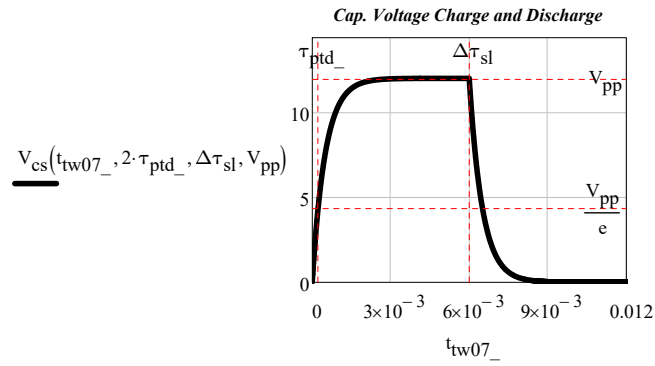


Pulses

- 26 Cap. Charge and Discharge Voltage Pulse

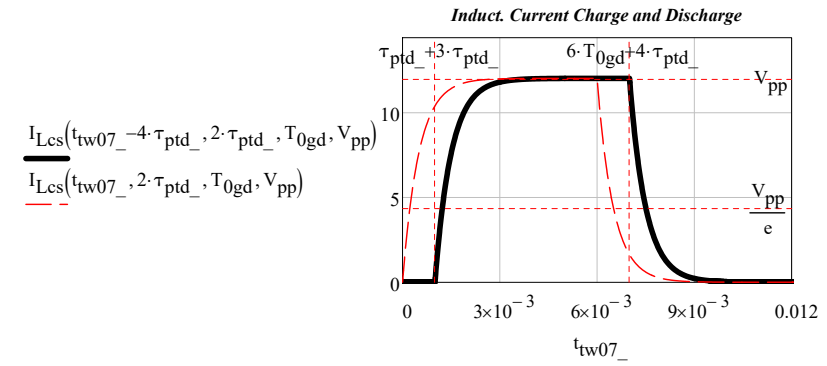
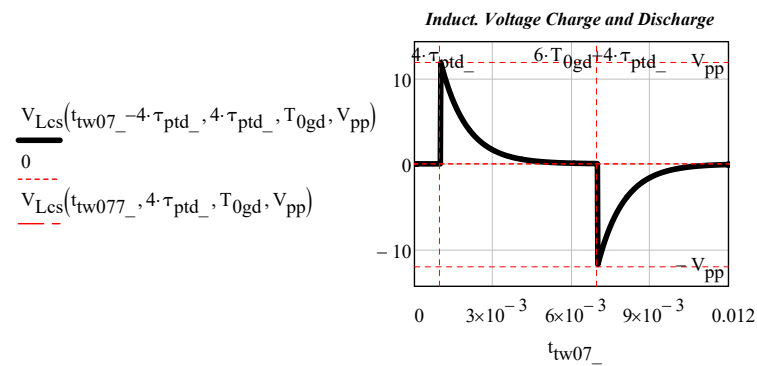


$$\Delta\tau_{sl} := 6 \cdot T_{0gd}$$



Pulses

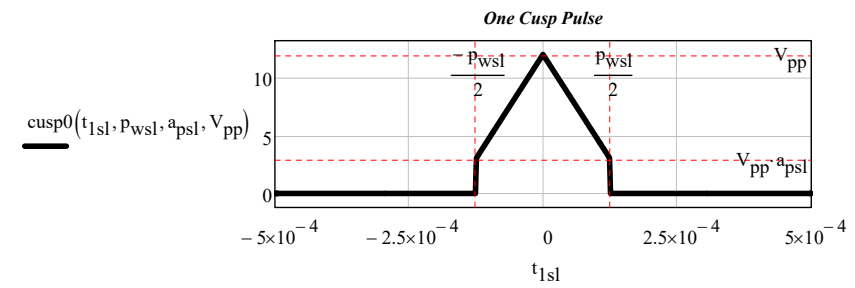
- 27 Induct. Charge and Discharge Pulse



Pulses

- 28 Triangular Cusp Pulse

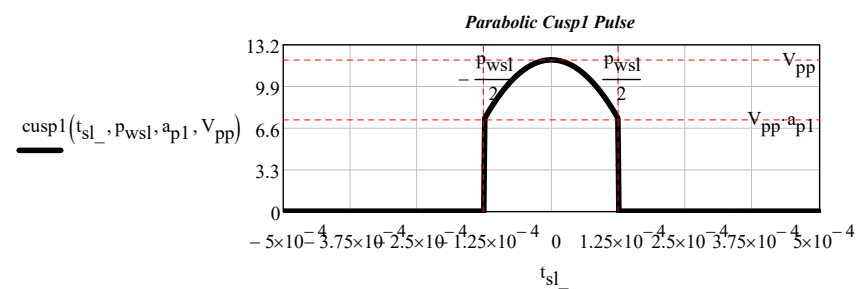
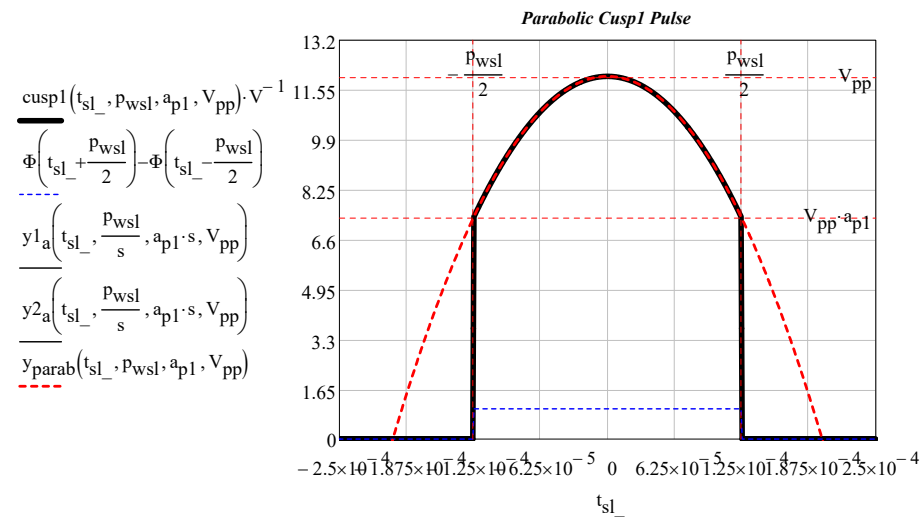
Signal amplitude:	$V_{pp} = 12 \cdot V$
Pulse width:	$P_{wsl} := \tau_{ptd_}$ $P_{wsl} = 250 \cdot \mu s$
Max pulse amplitude and cusp ratio:	$a_{psl} := \frac{1}{4}$ $a_{psl} < 1$
Cusp slope	$c_{ssl} := V_{pp} \cdot \frac{2 \cdot (1 - a_{psl})}{P_{wsl}}$ $c_{ssl} = 0.072 \cdot \frac{V}{\mu s}$



Pulses

- 29 Parabolic Cusp Pulse

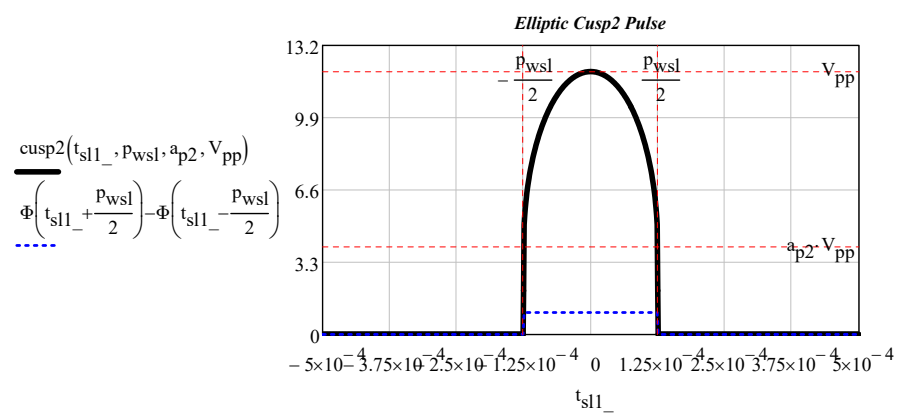
Max pulse amplitude and cusp ratio: $a_{p1} := 0.61$ $a_{p1} < 1$



Pulses

- 30 Elliptic Cusp Pulse

Max pulse amplitude and cusp ratio: $a_{p2} := \frac{1}{3}$ $a_{psl} < 1$



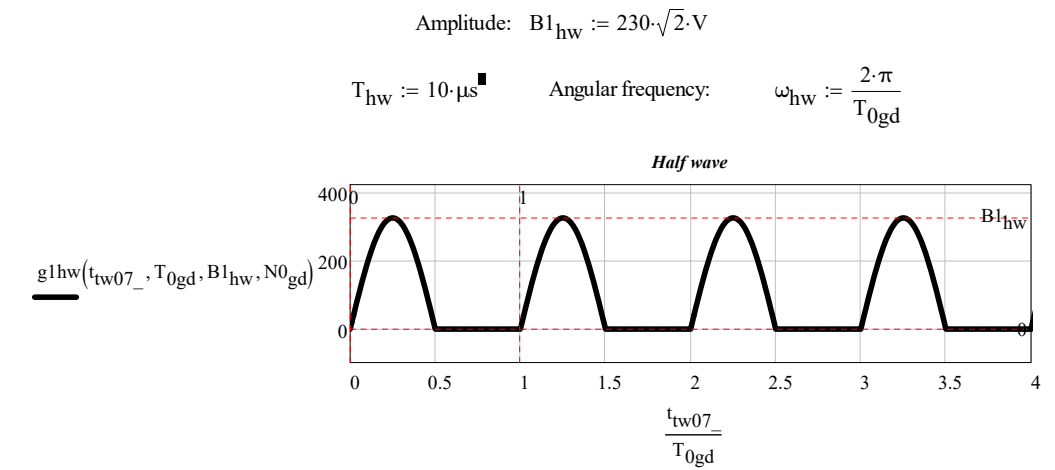
PERIODIC WAVEFORMS

TEST Waveforms

Periodic Waveforms Periodic Waveforms Periodic Waveforms

1) Half wave

Data file "general data.xmcd"



TEST Waveforms

Periodic Waveforms

2 Half wave filtered (Capacitive)

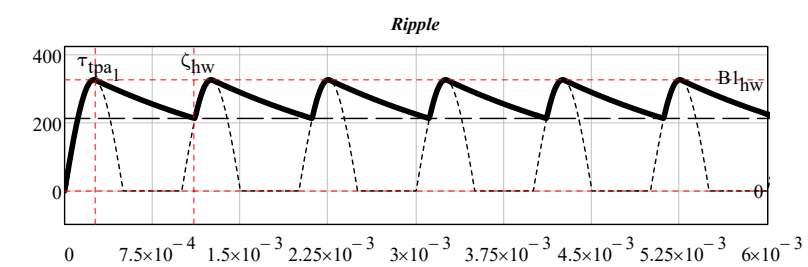
Max half wave amplitude: $B1_{hw} = 325.269 \cdot V$,
 Amplitude of the decreasing exponential for $t=0$: V_{pp} ,
 Exponential Time constant: $\tau_{hw1} := 2 \cdot T_{0gd}$,
 Period: $T_{hw} := T_{0gd}$, $T_{hw} = 1 \times 10^3 \cdot \mu s$,
 Pulsation: $\omega_{hw} = 6.283 \cdot \frac{\text{k rads}}{\text{sec}}$,
 Intersection abscissa between half wave and exponential: ζ (scalar),
 Tangent points abscissas between half wave and exponential: τ_{tpa} (vector)

$$\tau_{tpa_{k_{sl}}} := \frac{\text{atan}(-\omega_{hw} \cdot \tau_{hw1}) + k_{sl} \cdot \pi}{\omega_{hw}}$$

$$V_{tpv} := B1_{hw} \cdot \sin(\omega_{hw} \cdot \tau_{tpa_1}) \cdot e^{-\frac{\tau_{tpa_1}}{\tau_{hw1}}}$$

$$V_{tpv} = 369.746 \cdot V$$

$$\zeta_{hw} := Z01(\tau_{hw1}, \omega_{hw}, B1_{hw}, V_{tpv})$$

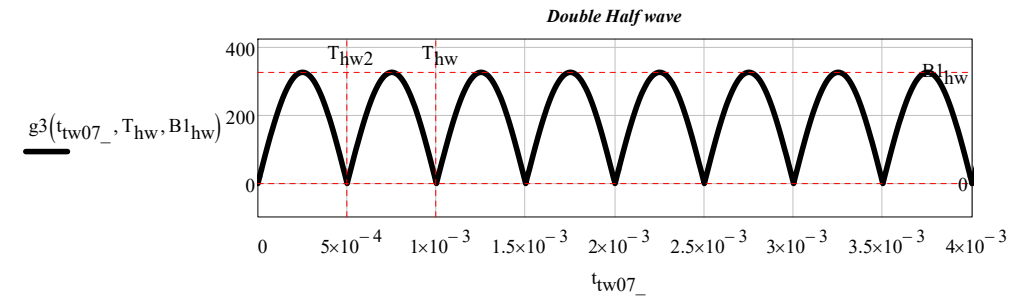


TEST Waveforms

Periodic Waveforms

3 Double Half wave

$$T_{hw2} := \frac{T_{hw}}{2} \quad \omega_{tw2} := \frac{\pi}{T_{hw2}} \quad g3(t_{sl}, T_{hw}, B1_{hw}) := \frac{B1_{hw}}{V} \cdot \left| \sin\left(\frac{2 \cdot \pi}{T_{hw}} \cdot t_{sl}\right) \right|$$



TEST Waveforms

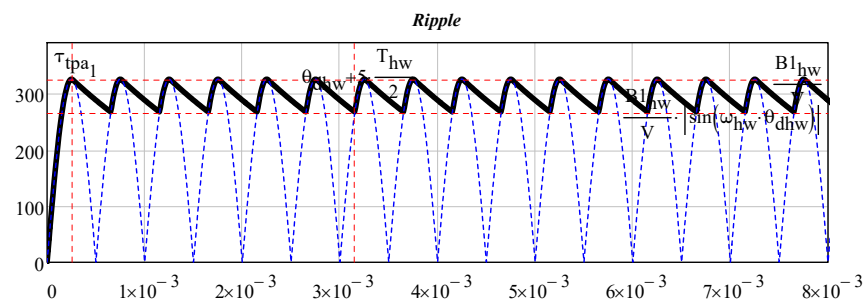
Periodic Waveforms

4 Double Half wave filtered

$$V_{ppt} := B1_{hw} \cdot \sin(\omega_{hw} \cdot \tau_{tpa1}) \cdot e^{-\frac{\tau_{tpa1}}{\tau_{hw1}}}$$

$$V_{ppt} = 369.746 \text{ V}$$

$$\theta_{dhw} := Z1(\tau_{hw1}, \omega_{hw}, B1_{hw}, V_{ppt}) \quad rip1 := \frac{\frac{B1_{hw}}{V} - \frac{B1_{hw}}{V} \cdot \left| \sin(\omega_{hw} \cdot \theta_{dhw}) \right|}{\frac{B1_{hw}}{V}}$$

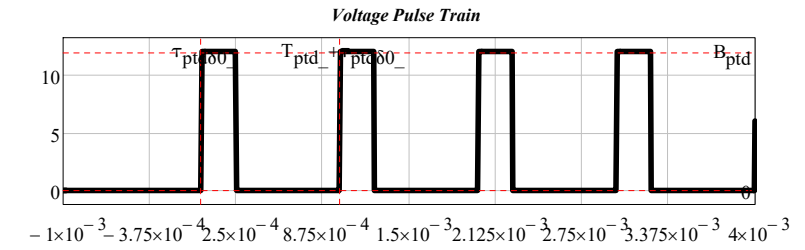


TEST Waveforms

Periodic Waveforms

5 Voltage Pulse Train

Data file " pulse_train_data.xmcd"



TEST Waveforms

Periodic Waveforms

6 RF Pulse Train

Data file "rf pulse data.xmcd"

Step amplitude.....: $V_{rfpd} := B_{ptd}, V_{rfpd} = 12 \cdot V$

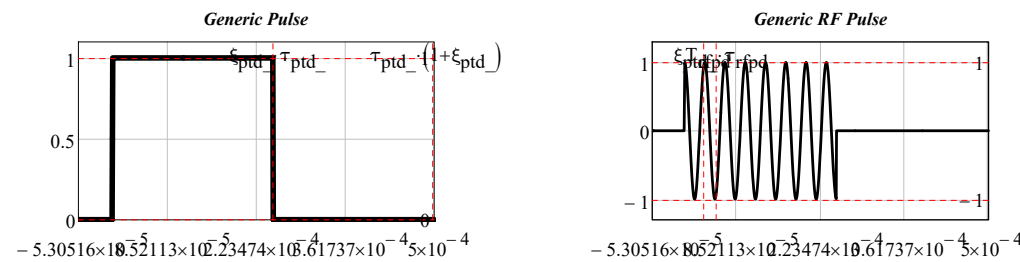
Signal frequency.....: $f_{rfpd} := 30 \cdot f_{ptd}$

Signal period.....: $T_{rfpd} := \frac{1}{f_{rfpd}}$

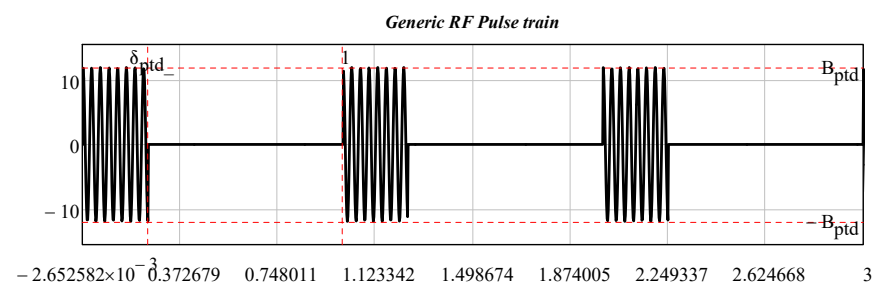
Signal angular frequency.....: $\omega_{rfpd} := 2 \cdot \pi \cdot f_{rfpd} \quad \omega_{rfpd} = 0.188 \cdot \frac{\text{Mrads}}{\text{sec}}$

time constant.....: $\tau_{rfpd} := \frac{10}{\omega_{rfpd}}, \tau_{rfpd} = 53.052 \cdot \mu\text{s}$

Rising edge delay: $\tau_{\delta rfpd} := 0 \cdot \text{ns}$



Average value: $v_{ptmrfsl} := B_{ptd} \cdot \delta_{ptd}$
 $t_{tw8} := -1 \cdot \tau_{ptd} - 1 \cdot \tau_{ptd} + \frac{4 \cdot \tau_{ptd} + \tau_{ptd}}{2000} \dots 4 \cdot \tau_{ptd}$



TEST Waveforms

Periodic Waveforms

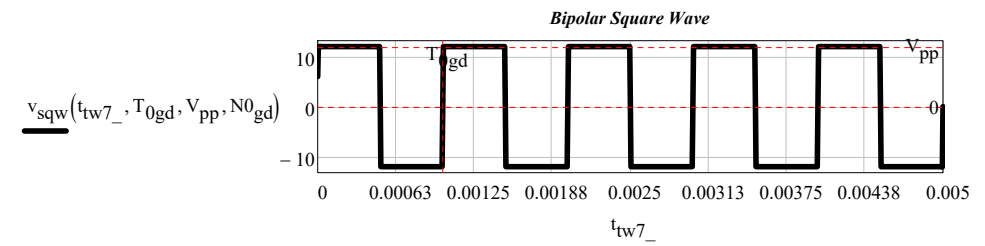
7 Bipolar Square Wave

Data file "pulse train data.xmcd"

Signal amplitude: $V_{pp} = 12 \cdot V$

Square wave period: $T_{0gd} = 1 \times 10^6 \cdot \text{ns}$

$\omega_{ptd} = 6.283 \times 10^{-6} \cdot \frac{\text{Grads}}{\text{sec}}$



TEST Waveforms

Periodic Waveforms

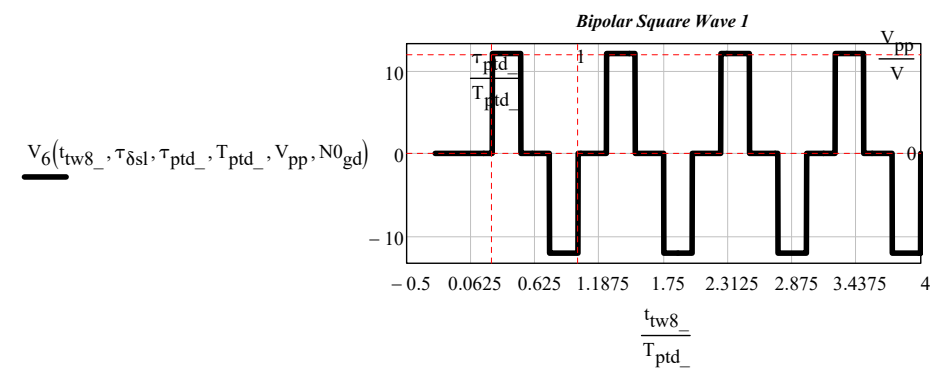
8 Bipolar Square Wave 1

Data file "pulse train data.xmcd"

Signal amplitude: $V_{pp} = 12 \cdot V$

Square wave period: $T_{0gd} = 1 \times 10^6 \cdot \text{ns}$

$\omega_{ptd} = 6.283 \times 10^{-6} \cdot \frac{\text{Grads}}{\text{sec}}$



TEST Waveforms

Periodic Waveforms

9 Staircase 1 Voltage Pulse Train

Description of the Function's parameters: $v_{stcp}(t_{s1}, \text{period}, \text{signal_amplitude}, \text{number_of_steps})$
 $: v_{stc}(t_{s1}, \text{step_length}, \text{signal_amplitude}, \text{number_of_steps})$

For data, see the worksheet "staircase pulse data.xmcd"

Period: $T_{stcpt} := (m1_{steps} + 1) \cdot T_{1stpl}$

Duty Cycle: $\delta_{stcpt} := \frac{m1_{steps} \cdot T_{1stpl}}{T_{stcpt}}$

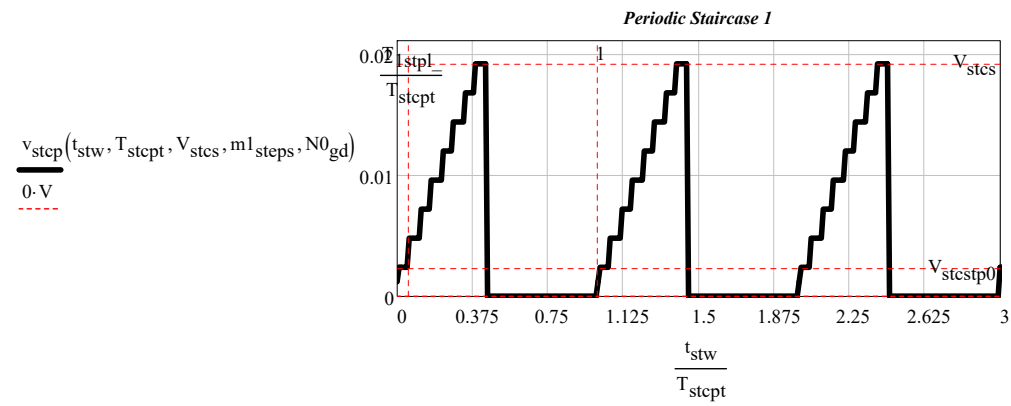
Staircase frequency: $f_{stcpt} := \frac{1}{T_{stcpt}}$

$\omega_{stcpt} := 2 \cdot \pi \cdot f_{stcpt}$

Number of periods shown: $n_p := 20$

$v_{stcptasl} := \frac{V_{stcs}}{2 \cdot m1_{steps} \cdot (m1_{steps} + 1)} \cdot \sum_{k=1}^{m1_{steps}} (m1_{steps} - k + 1) = 4.8 \cdot \text{mV}$

$t_{stw} := 0 \cdot T_{stcpt}, 0 \cdot T_{stcpt} + \frac{10 \cdot T_{stcpt}}{1000} \dots 10 \cdot T_{stcpt}$



TEST Waveforms

Periodic Waveforms

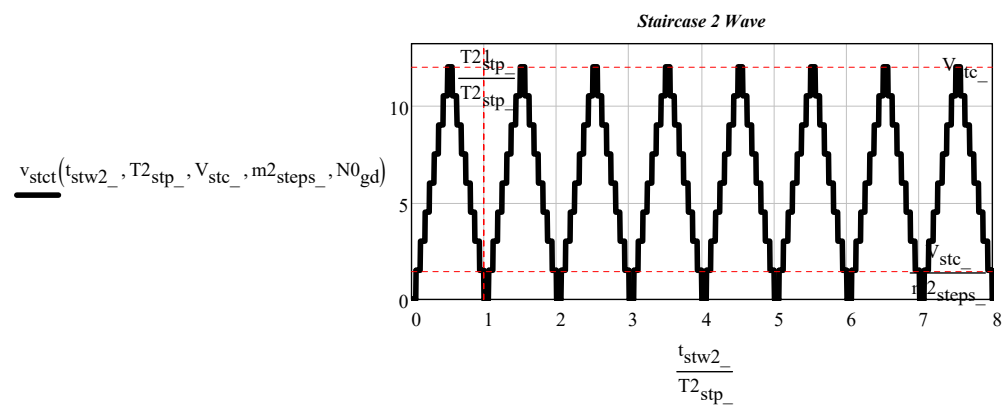
10 Staircase 2 Voltage Pulse Train

Description of the Function's parameters: $v_{stct}(time, period, max_amplitude, number_of_steps)$

$$v_{stct}(t_{s1}, step_length, signal_amplitude, number_of_steps)$$

For data, see the worksheet "staircase 2 pulse data.xmcd"

$$t_{stw2_} := 0 \cdot T_{2stp_} + 0 \cdot T_{2stp_} + \frac{10 \cdot T_{2stp_}}{2000} \dots 10 \cdot T_{2stp_}$$



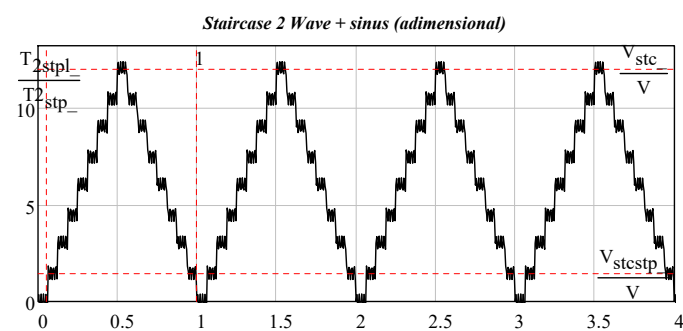
TEST Waveforms

Periodic Waveforms

11 Staircase 2 Voltage Pulse Train + sinus

Description of the Function's parameters: $V_{stcsin}(t_{s1}, period, max_amplitude, number_of_steps)$

For data, see the worksheet "staircase 2 pulse data.xmcd"



TEST Waveforms

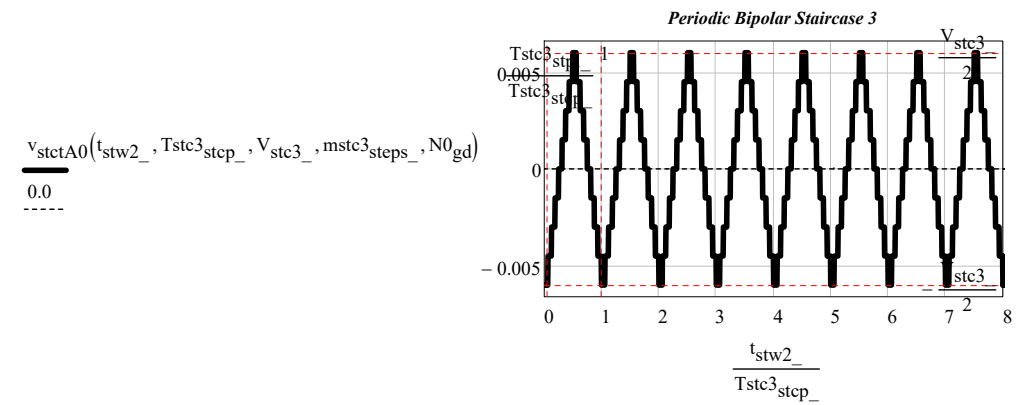
Periodic Waveforms

12 Staircase 3 Bipolar Voltage Pulse Train

Description of the Function's parameters: $v_{stct}(t_{s1}, period, step_amplitude, number_of_steps)$

$$: v_{stctA0}(t_{s1}, (period, step_amplitude, number_of_steps))$$

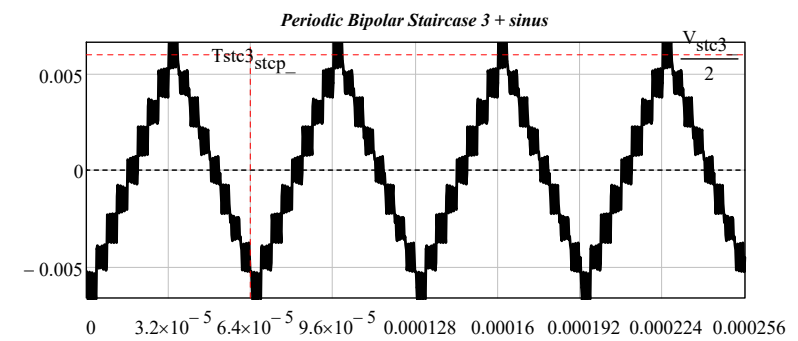
You can find the data in "staircase 3 pulse data.xmcd"



TEST Waveforms

Periodic Waveforms

13 Staircase 3 Bipolar Voltage Pulse Train + sinus



TEST Waveforms

Periodic Waveforms

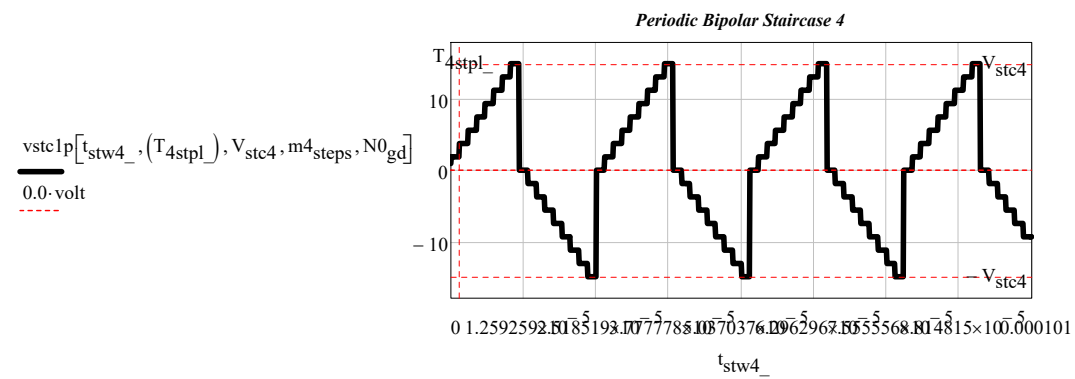
14 Staircase 4 Bipolar Voltage Pulse Train

Description of the Function's parameters : $v_{stc1p}(time, step_length, step_amplitude, number_of_steps)$

To modify data, see the worksheet "staircase 4 pulse data.xmcd"

Amplitude:	$V_{stc4} = 15\text{ V}$
Step length:	$T_{4stp1_} = 1.481 \cdot \mu\text{s}$
Number of steps:	$m_{4steps} = 8$
Time constant:	$\tau_{4_} = 74.074 \cdot \text{ns}$
Period:	$T_{4stcp_} = 0.025 \cdot \text{ms}$
Frequency:	$f_{44stcp_} = 3.971 \times 10^4 \cdot \text{Hz}$

$$\omega_{44stcp_} = 2.495 \times 10^5 \frac{\text{rad}}{\text{sec}}$$



TEST Waveforms

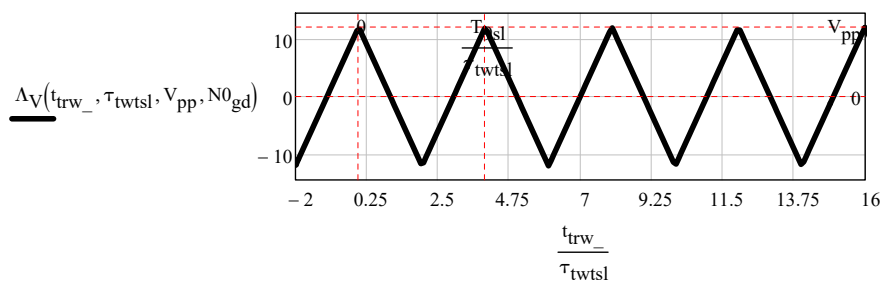
Periodic Waveforms

15 Bipolar Triangular Voltage Wave

Description of the Function's parameters : $\Delta V(\text{time, triangle half base, triangle amplitude})$

Time constant: $\tau_{twtsl} := 1 \cdot \mu\text{s}$
 Period: $T_{9sl} := 4 \cdot \tau_{twtsl}$ $f_{9sl} := \frac{1}{T_{9sl}}$

$$t_{trw_} := -1 \cdot T_{9sl}, -1 \cdot T_{9sl} + \frac{20 \cdot T_{9sl} + 1 \cdot T_{9sl}}{1000} \dots 20 \cdot T_{9sl}$$

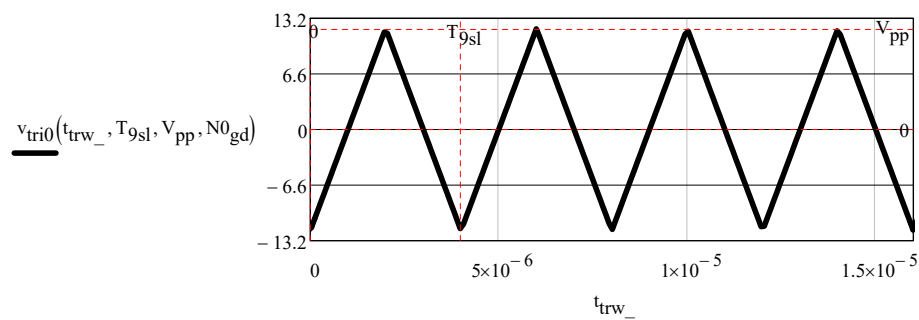


Bipolar Triangular Voltage Wave Built using the Step Function

Signal amplitude: $V_{pp} = 12 \cdot \text{V}$
 Time constant: $\tau_{twtsl} = 1 \cdot \mu\text{s}$
 Period: $T_{9sl} = 4 \cdot \mu\text{s}$

$$\omega_{9sl} := 2 \cdot \pi \cdot f_{9sl} \quad \omega_{9sl} = 1.571 \times 10^6 \frac{\text{rad}}{\text{sec}}$$

$$N0_{gd} = 256$$



TEST Waveforms

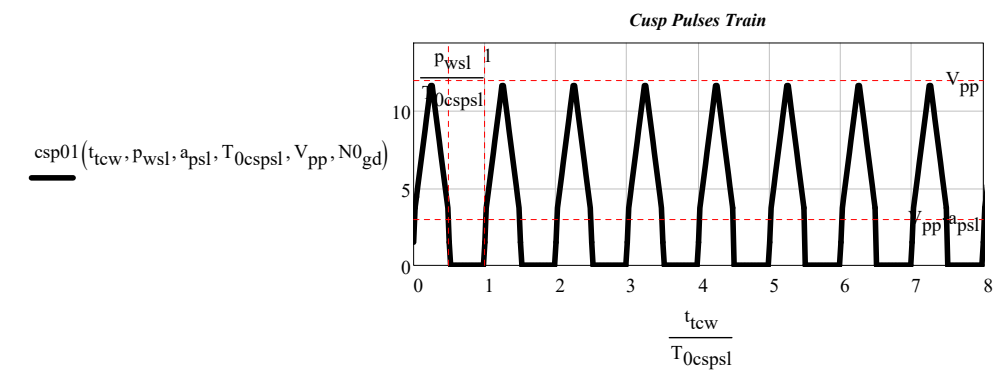
Periodic Waveforms

16 Triangular Cusps Voltage Pulse Train

Signal amplitude: $V_{pp} = 12 \cdot \text{V}$
 Pulse width: $P_{wsl} = 250 \cdot \mu\text{s}$
 Period: $T_{0cspsl} := 2 \cdot P_{wsl}$

Max pulse amplitude and cusp ratio:
 $a_{psl} = 0.25 \quad a_{psl} < 1$

$$t_{tcw} := 0 \cdot T_{0cspsl}, 0 \cdot T_{0cspsl} + \frac{10 \cdot T_{0cspsl} - 0 \cdot T_{0cspsl}}{500} \dots 10 \cdot T_{0cspsl}$$



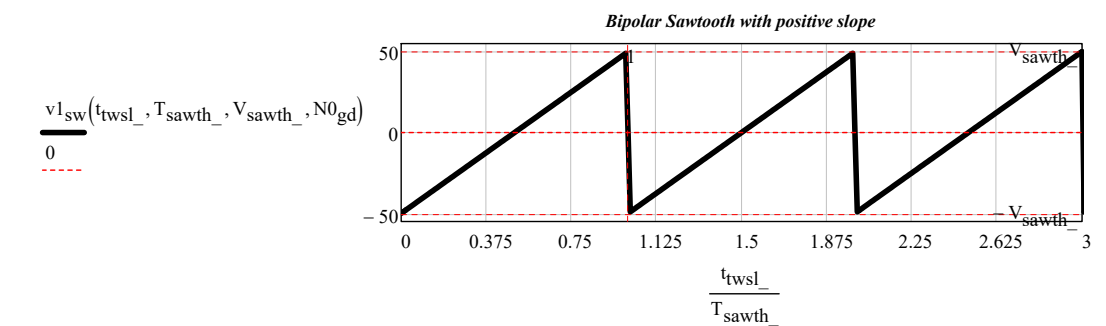
TEST Waveforms

Periodic Waveforms

17 Bipolar Sawtooth with positive slope Pulse Train

Period: $T_{sawth_} := 1 \cdot \delta_{sawth_}$
 Frequency: $f_{sawth_} := \frac{1}{T_{sawth_}} \quad f_{sawth_} = 1 \cdot \text{MHz}$
 $\omega_{sawth_} := 2 \cdot \pi \cdot f_{sawth_} \quad \omega_{sawth_} = 6.283 \cdot \frac{\text{Mrads}}{\text{sec}}$

$$t_{twsl_} := -T_{sawth_} \cdot 0, T_{sawth_} \cdot 0 + \frac{5 \cdot T_{sawth_} + T_{sawth_} \cdot 0}{500} \dots 5 \cdot T_{sawth_}$$



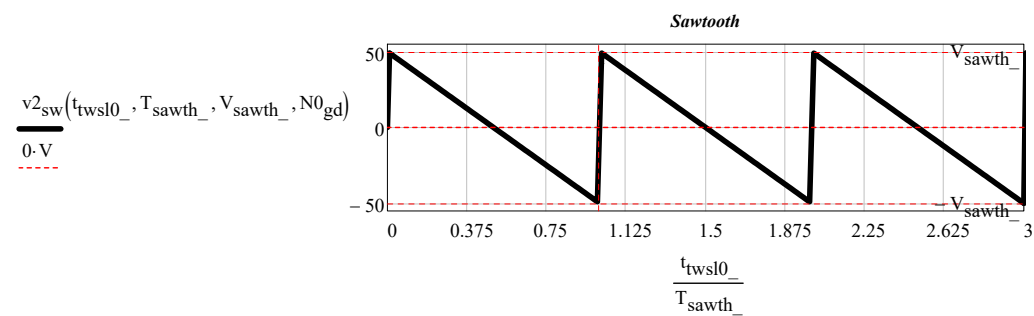
TEST Waveforms

Periodic Waveforms

18 Bipolar Sawtooth with negative slope Pulse Train

Amplitude: $V_{\text{sawth}_-} = 50 \cdot \text{V}$
 Sawtooth length: $\delta_{\text{sawth}_-} = 1 \cdot \mu\text{s}$
 Slope: $\text{sp}_{\text{sawth}_-} = 50 \cdot \frac{\text{V}}{\mu\text{s}}$
 Period: $T_{\text{sawth}_-} = 1 \cdot \mu\text{s}$
 Frequency: $\frac{1}{T_{\text{sawth}_-}} = 1 \cdot \text{MHz}$

$$t_{\text{twsl0}_-} := -T_{\text{sawth}_-} \cdot 0, T_{\text{sawth}_-} \cdot 0 + \frac{5 \cdot T_{\text{sawth}_-} + T_{\text{sawth}_-} \cdot 0}{500} \dots 5 \cdot T_{\text{sawth}_-}$$



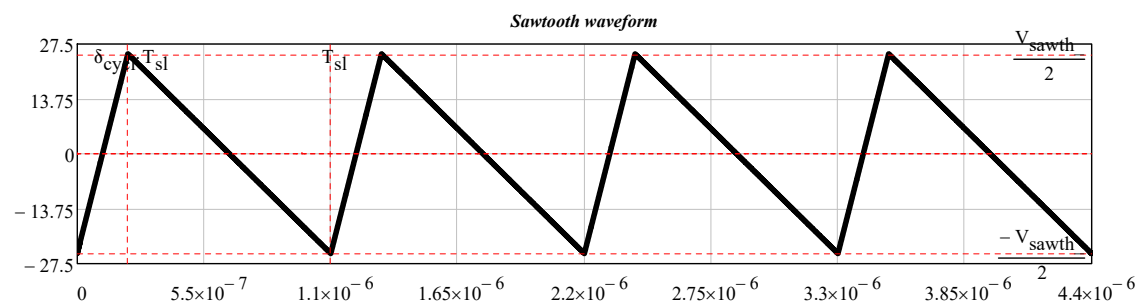
TEST Waveforms

Periodic Waveforms

19 Bipolar Sawtooth with adjustable rising and falling edges Pulse Train

$\tau_{\text{cycl}} = 220 \cdot \text{ns}$
 $T_{\text{sl}} = 1.1 \cdot \mu\text{s}$
 $\delta_{\text{cycl}} = 20 \cdot \%$
 $\omega_{0\text{sl}} = 5.712 \cdot \frac{\text{Mrads}}{\text{sec}}$
 $V1_s(t, T_{\text{sl}}, \delta_{\text{cycl}}, V_{\text{pp}}, N_{\text{gd}})$

$$t_{\text{sl2}_-} := 0 \cdot T_{\text{sl}}, 0 \cdot T_{\text{sl}} + \frac{4 \cdot T_{\text{sl}}}{10000} \dots 4 \cdot T_{\text{sl}}$$



TEST Waveforms

Periodic Waveforms

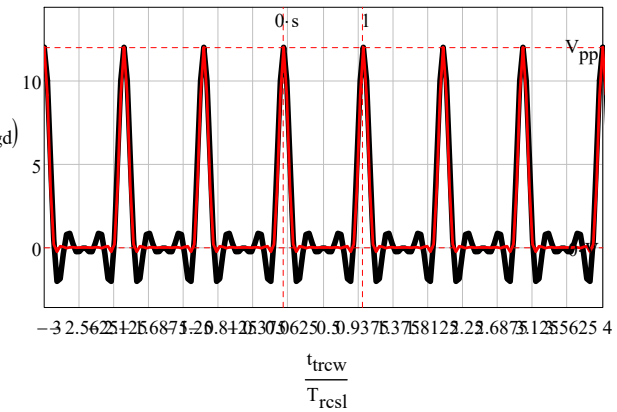
20 Dimensionless (RC) Pulse Train

$T_{0\text{gd}} = 1 \times 10^{-3} \cdot \mu\text{s}$ $Bw_{\text{rcsl}} = 650 \cdot \text{Hz}$

$$\tau_{\text{rcsl}} := \frac{T_{0\text{gd}}}{8}$$

$$t_{\text{trcw}} := -20 \cdot T_{0\text{gd}}, -20 \cdot T_{0\text{gd}} + \frac{20 \cdot T_{0\text{gd}} + 20 \cdot T_{0\text{gd}}}{1000} \dots 20 \cdot T_{0\text{gd}}$$

Raised-Cosine (RC) Pulse Train



$$\frac{V_{\text{pp}} t_{\text{rc}}(t_{\text{trcw}}, \alpha_{\text{rcsl}}, \tau_{\text{rcsl}}, T_{0\text{gd}}, V_{\text{pp}}, N_{0\text{gd}})}{V_{\text{pp}} t_{\text{rc}}(t_{\text{trcw}}, 1, \tau_{\text{rcsl}}, T_{0\text{gd}}, V_{\text{pp}}, N_{0\text{gd}})}$$

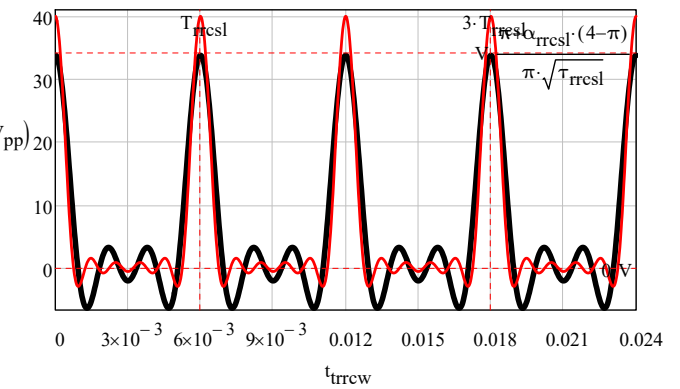
TEST Waveforms

Periodic Waveforms

21 Root Raised-Cosine (RC) Pulse Train

$\alpha_{\text{rrcsl}} = 0.3$

Root Raised-Cosine (RRC) Pulse Train



$$\frac{V_{\text{rrc}}(t_{\text{trcw}}, \alpha_{\text{rrcsl}}, \tau_{\text{rrcsl}}, T_{\text{rrcsl}}, N_{0\text{gd}}, V_{\text{pp}})}{V_{\text{rrc}}(t_{\text{trcw}}, 1, \tau_{\text{rrcsl}}, T_{\text{rrcsl}}, N_{0\text{gd}}, V_{\text{pp}})}$$

$$V_{\text{rrc}}(0, \alpha_{\text{rrcsl}}, \tau_{\text{rrcsl}}, T_{\text{rrcsl}}, N_{0\text{gd}}, V_{\text{pp}}) = 33.806$$

TEST Waveforms

Periodic Waveforms

22 AM test signal (single tone)

Carrier Amplitude: $A1_{\text{sl}} := 20 \cdot \text{volt}$

Modulating signal's amplitude: $B1_{\text{sl}} := 12 \cdot \text{volt}$ $\omega_{0\text{gd}} = 6.283 \cdot \frac{\text{krads}}{\text{s}}$

$$\omega_{1\text{csl}} := 15 \cdot \omega_{0\text{gd}} \quad T1_{\text{csl}} := \frac{2 \cdot \pi}{\omega_{1\text{csl}}} \quad \omega_{1\text{msl}} := \frac{\omega_{1\text{csl}}}{10} \quad T1_{\text{msl}} := \frac{2 \cdot \pi}{\omega_{1\text{msl}}} \quad f1_{\text{msl}} := \frac{\omega_{1\text{msl}}}{2 \cdot \pi} \quad f15_{\text{sl}} := \frac{\omega_{1\text{csl}}}{2 \cdot \pi}$$

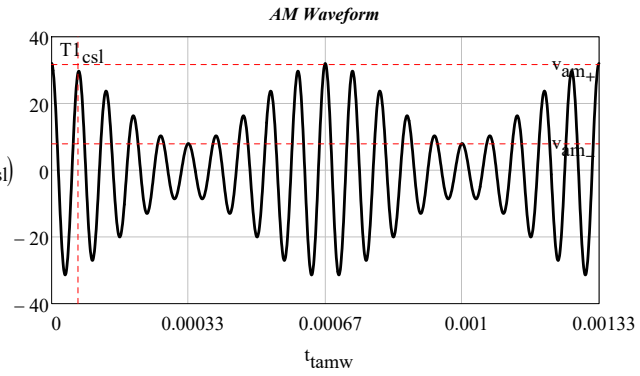
$$\omega_{1\text{csl}} = 94.248 \cdot \frac{\text{krads}}{\text{sec}} \quad \frac{\omega_{1\text{csl}}}{\omega_{1\text{msl}}} = 10$$

$$v_{am+} := A1_{sl} + B1_{sl} \quad v_{am-} := A1_{sl} - B1_{sl} \quad A1_{sl} = v_{am+} + v_{am-} \quad B1_{sl} = v_{am+} - v_{am-}$$

$$v_{am+} = 32\text{-volt} \quad m_{amsl} := \frac{v_{am+} - v_{am-}}{v_{am+} + v_{am-}} \quad m_{amsl} = 60\% \quad \frac{B1_{sl}}{A1_{sl}} = 60\%$$

$$v_{am-} = 8\text{-volt}$$

$$t_{tamw} := -T0gd \cdot 3, -T0gd \cdot 3 + \frac{20 \cdot T1_{csl} + T0gd \cdot 3}{5000} \dots 20 \cdot T1_{csl}$$



$$V2am(t_{tamw}, \omega1_{msl}, \omega1_{csl}, A1_{sl}, m_{amsl})$$

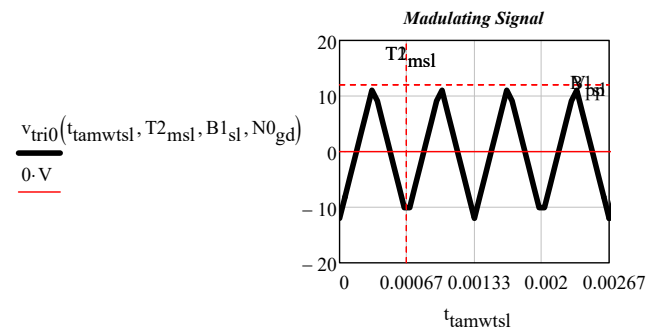
TEST Waveforms

Periodic Waveforms

23 AM test signal (triangular wave)

$$\omega2_{msl} := \frac{\omega1_{csl}}{10} \quad T2_{msl} := \frac{2 \cdot \pi}{\omega2_{msl}}$$

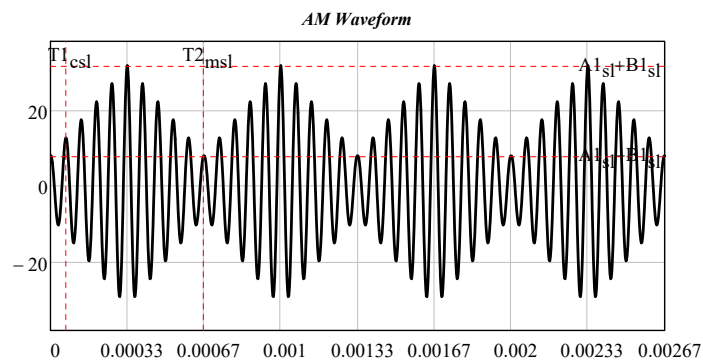
$$t_{tamwtsl} := 0\text{-sec}, 40 \cdot \frac{T2_{msl}}{500} \dots 40 \cdot T2_{msl}$$



$$V_{tri0}(t_{tamwtsl}, T2_{msl}, B1_{sl}, N0_{gd})$$

0 V

$$t_{twsl} := -T2_{msl} \cdot 3, -T2_{msl} \cdot 3 + \frac{8 \cdot T2_{msl} + T0gd \cdot 3}{500} \dots 8 \cdot T2_{msl}$$



TEST Waveforms

Periodic Waveforms

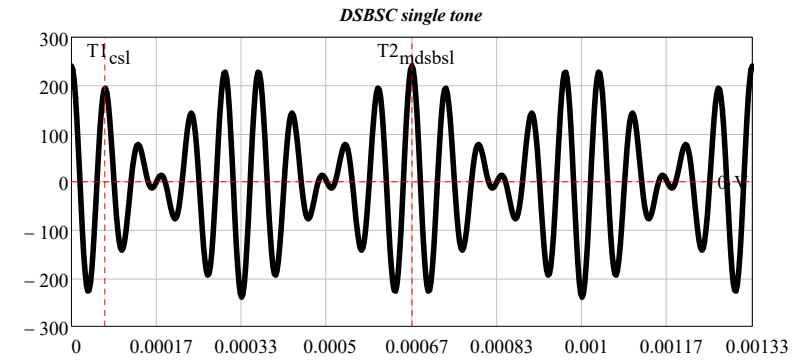
24 AM DSBSC test signal (single tone)

$$\omega2_{msl} := \frac{\omega1_{csl}}{10} \quad T2_{mdsbsl} := \frac{2 \cdot \pi}{\omega2_{msl}} \quad \omega2_{msl} = \frac{2 \cdot \pi}{T2_{mdsbsl}} \frac{A1_{sl} \cdot B1_{sl}}{2} = 120 \cdot \text{volt}^2$$

$$\omega1_{csl} = 0.094 \frac{\text{Mrads}}{\text{sec}} \quad \omega2_{msl} = 9.425 \times 10^{-3} \frac{\text{Mrads}}{\text{sec}} \quad f2_{msl} := \frac{1}{T2_{msl}} \quad f1_{csl} := \frac{\omega1_{csl}}{2 \cdot \pi}$$

$$T1_{csl} := \frac{1}{f1_{csl}} \quad \nu_{sl} := 20$$

$$t_{tdsbw} := 0\text{-sec}, \nu_{sl} \cdot \frac{T1_{csl}}{500} \dots \nu_{sl} \cdot T1_{csl}$$



TEST Waveforms

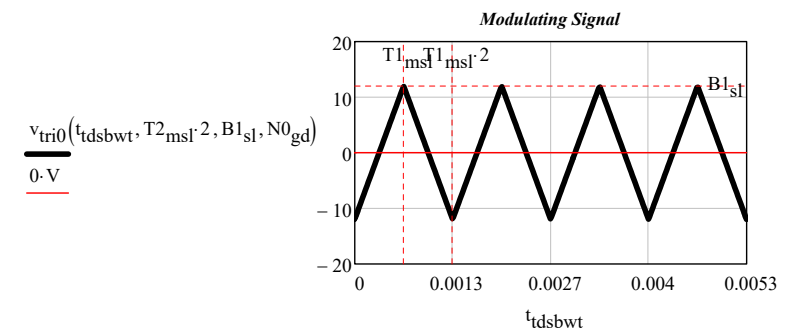
Periodic Waveforms

25 AM DSBSC test signal (triangular wave)

$$T18 := T2_{mdsbsl}$$

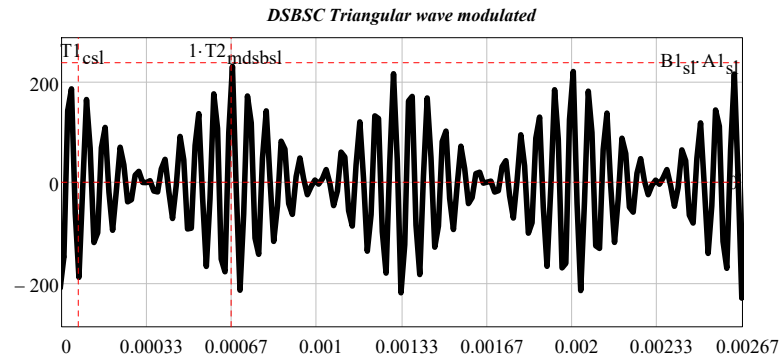
$$f18 := \frac{1}{T18}$$

$$t_{tdsbwt} := -T18 \cdot 3, -T18 \cdot 3 + \frac{8 \cdot T18 + T18 \cdot 3}{500} \dots 8 \cdot T18$$



$$V_{tri0}(t_{tdsbwt}, T2_{msl} \cdot 2, B1_{sl}, N0_{gd})$$

0 V



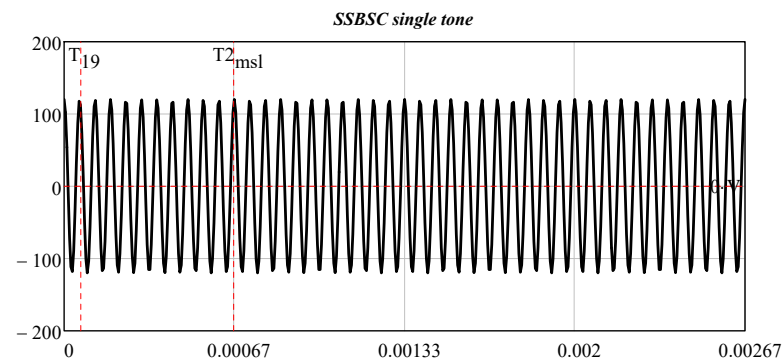
TEST Waveforms

Periodic Waveforms

26 AM SSBSC test signal (single tone)

$$f_{19} := \frac{\omega_{csl}}{2 \cdot \pi} \quad T_{19} := \frac{1}{f_{19}}$$

$$t_{ssbw} := 0 \cdot \text{sec} + \frac{4 \cdot T_{2msl}}{500} \dots 4 \cdot T_{2msl}$$

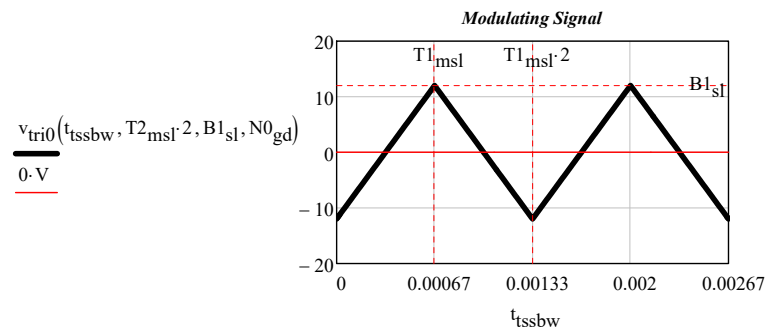


TEST Waveforms

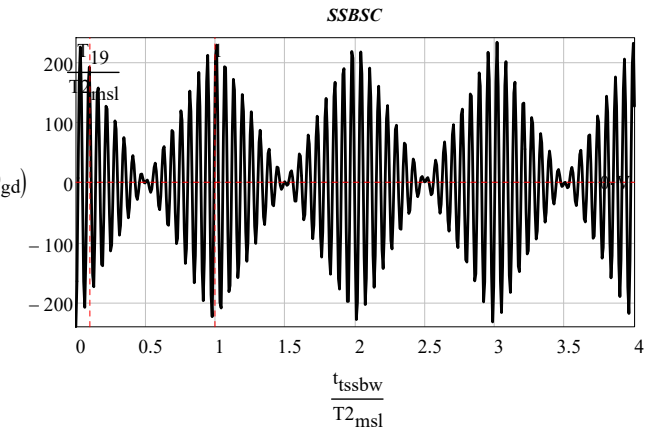
Periodic Waveforms

27 AM SSBSC test signal (triangular wave)

$$f_{20} := \frac{10}{T_{1csl}}$$



$$\frac{v_{tri0}(t_{ssbw}, T_{2msl} \cdot 2, B_{1sl}, N_{0gd})}{0 \cdot V}$$



$$\frac{V_{7ssbsc}(t_{ssbw}, f_{20}, f_{2msl}, A_{1sl}, B_{1sl}, N_{0gd})}{0 \cdot V}$$

TEST Waveforms

Periodic Waveforms

28 FM test signal (single tone) (change data in FM data.xmcd)

- Carrier Amplitude:.....: $A_{fm} = 200 \cdot \text{mV}$
- Carrier Frequency.....: $f_{cfm} = 3 \cdot \text{MHz}$
- Carrier period.....: $T_{cfm} = 0.333 \cdot \mu\text{s}$
- Angular frequency of the carrier.....: $\omega_{cfm} = 18.85 \cdot \frac{\text{Mrads}}{\text{sec}}$
- Amplitude of the single tone modulating signal.....: $B_{fmm} = 15 \cdot \text{V}$
- Period of the modulating signal.....: $T_{fmm} = 6.667 \cdot \mu\text{s}$
- Frequency of the single tone modulating signal.....: $f_{fmm} := \frac{1}{T_{fmm}}$
- Angular frequency of the single tone modulating signal: $\omega_{fmm} = 0.942 \cdot \frac{\text{Mrads}}{\text{sec}}$

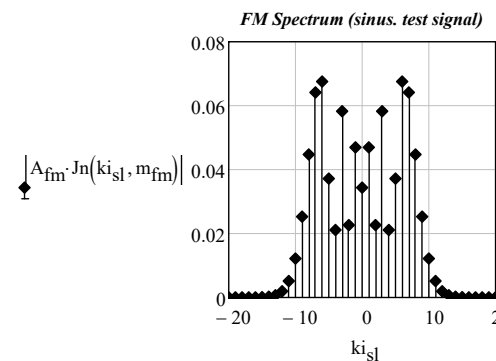
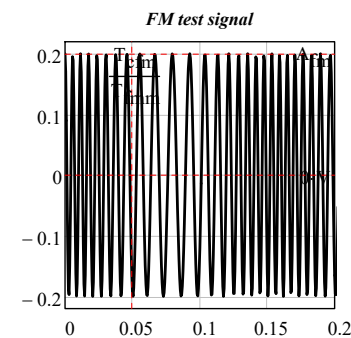
Frequency modulation index: $m_{fm} = 8$

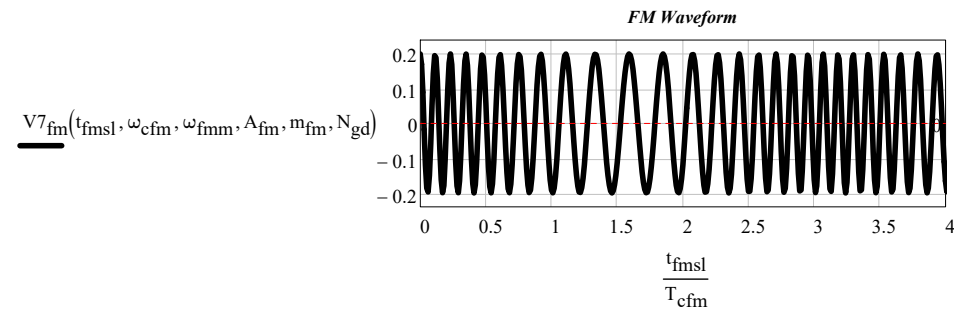
$$\frac{T_{fmm}}{T_{cfm}} = 20 \quad \frac{\omega_{cfm}}{\omega_{fmm}} = 20$$

$m_{fm} = 8$

$k_{i_{sl}} := -30 \dots 30$

$$t_{fmsl} := T_{fmm} \cdot 0, T_{fmm} \cdot 0 + \frac{10 \cdot T_{fmm} - T_{fmm} \cdot 0}{20000} \dots 10 \cdot T_{fmm}$$

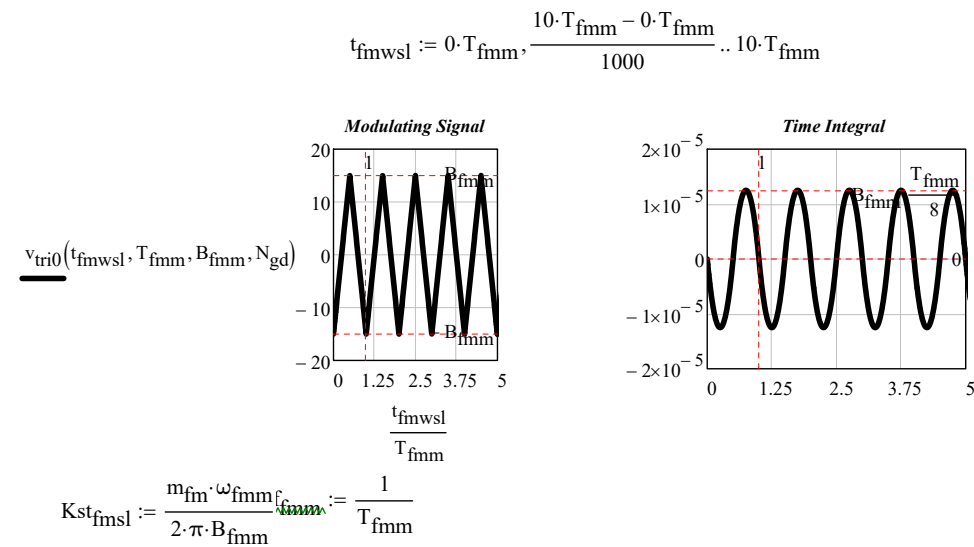




TEST Waveforms

Periodic Waveforms

29 FM test signal (triangular wave)



TEST Waveforms

Periodic Waveforms

30 PM test signal (single tone)

Carrier Amplitude: $A_{pm} = 20 \cdot V$

Carrier Frequency: $f_{cpm} = 0.12 \cdot MHz$

Carrier period: $T_{cpm} = 8.333 \times 10^3 \cdot ns$

Angular frequency of the carrier: $\omega_{cpm} = 7.54 \times 10^{-4} \cdot \frac{Grads}{sec}$

Amplitude of the modulating signal: $B_{pm} = 5 \cdot V$

Modulating signal period: $T_{pmm} = 83.333 \cdot \mu s$

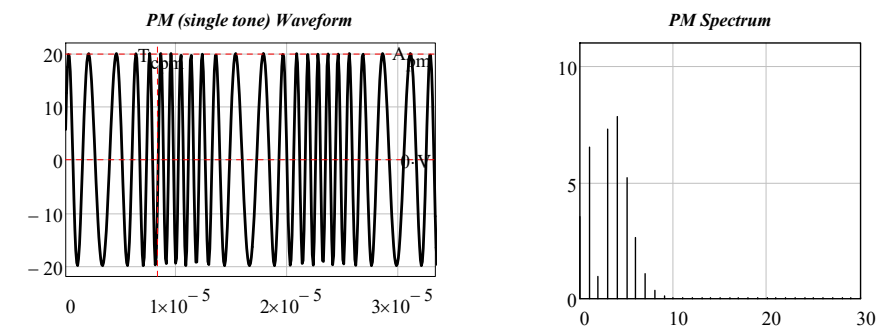
Frequency of the harmonic modulating signal: $f_{pmm} = 0.012 \cdot MHz$, $\frac{T_{pmm}}{T_{cpm}} = 10$

Angular frequency of the modulating signal: $\omega_{pmm} = 0.075 \cdot \frac{Mrads}{sec}$

Phase modulation index: $m_{pm} = 5 \cdot rad$

Phase-sensitivity factor: $k_{pm} = 1 \cdot \frac{rad}{V}$

$$t_{pm} := T_{cpm} \cdot 0, T_{cpm} \cdot 0 + \frac{40 \cdot T_{cpm} - 0 \cdot T_{cpm}}{4000} \dots 40 \cdot T_{cpm} \quad m_{pm} = 5 \quad A_{pm} = 20 \cdot V$$



TEST Waveforms

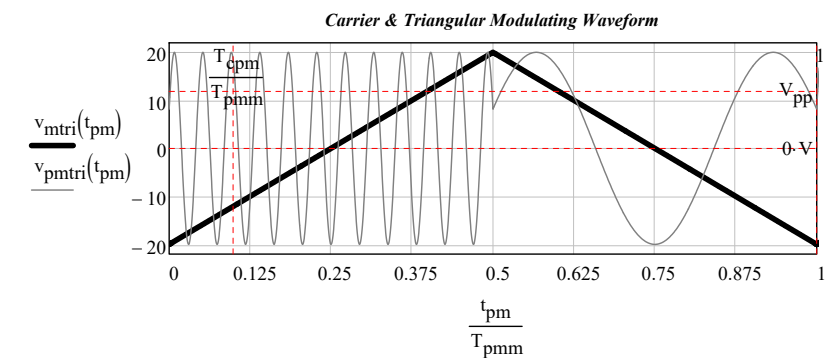
Periodic Waveforms

31 PM test signal (triangular wave)

$$v_{mtri}(t_{sl}) := v_{tri0}(t_{sl}, T_{pmm}, A_{pm}, N_{0gd})$$

$$v_{pmtri}(t_{sl}) := A_{pm} \cdot \cos(\omega_{cpm} \cdot t_{sl} + k_{pm} \cdot v_{mtri}(t_{sl}))$$

$$t_{pm} := T_{pmm} \cdot 0, T_{pmm} \cdot 0 + \frac{5 \cdot T_{pmm} - 0 \cdot T_{pmm}}{10000} \dots 5 \cdot T_{pmm}$$



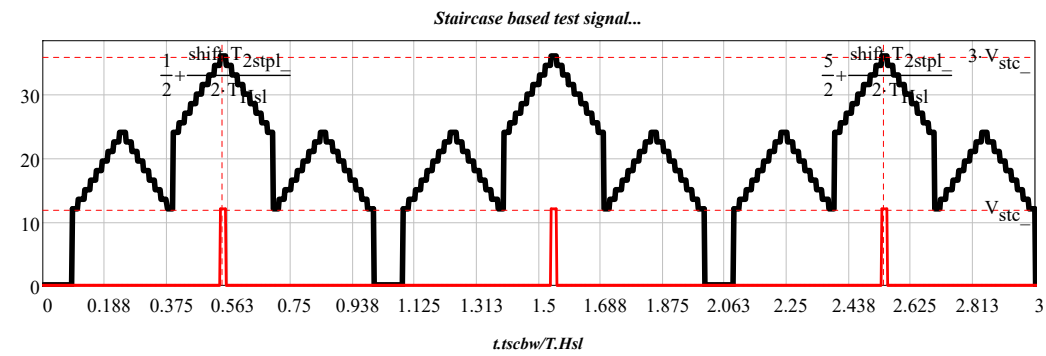
TEST Waveforms

Periodic Waveforms

32 Staircase based test signal

$$\text{shift} := 5 \quad m2_{\text{steps}} = 8 \quad T_{2\text{stpl}} = 4 \times 10^{-6} \text{ s} \quad mstc3_{\text{steps}} = 8$$

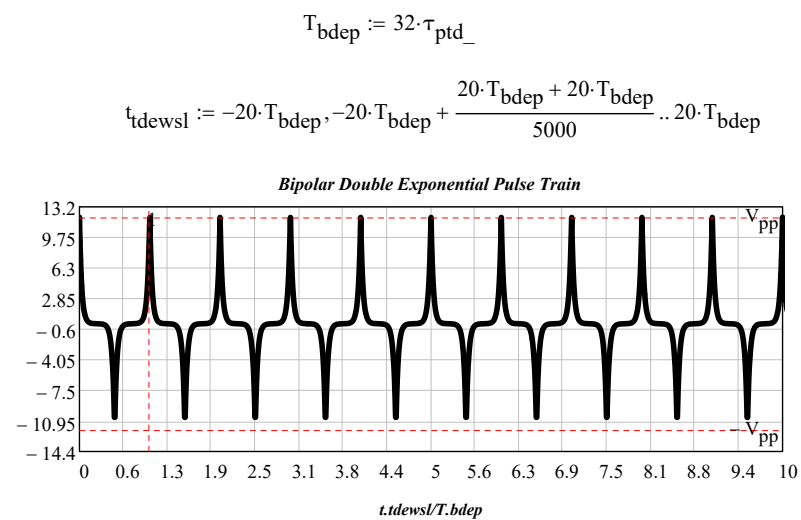
$$T_{\text{Hsl}} := (6 \cdot m2_{\text{steps}} + \text{shift} + 3) \cdot T_{2\text{stpl}} \quad t_{\text{scbw}} := 0 \cdot T_{\text{Hsl}}, 0 \cdot T_{\text{Hsl}} + \frac{5 \cdot T_{\text{Hsl}}}{2000} \dots 5 \cdot T_{\text{Hsl}}$$



TEST Waveforms

Periodic Waveforms

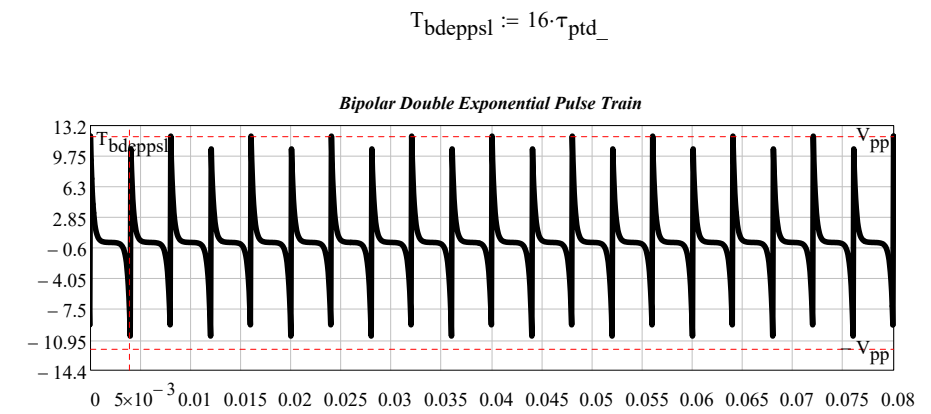
33 Bipolar Double Exponential Pulse Train



TEST Waveforms

Periodic Waveforms

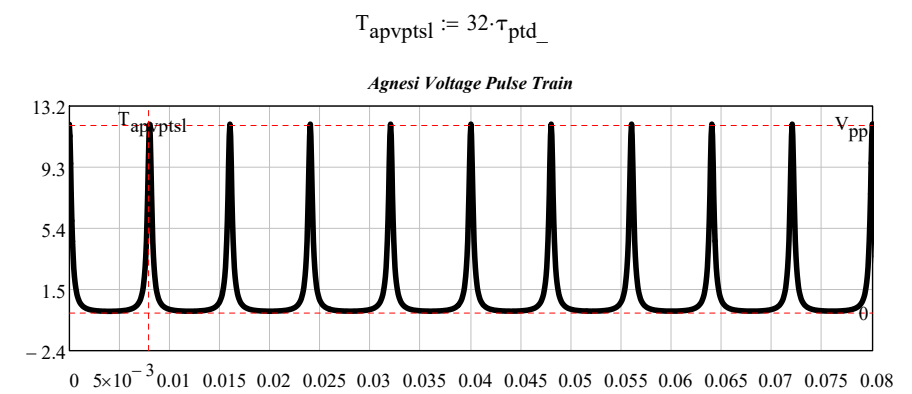
34 Bipolar Double Exponential Odd symmetric Pulse Train



TEST Waveforms

Periodic Waveforms

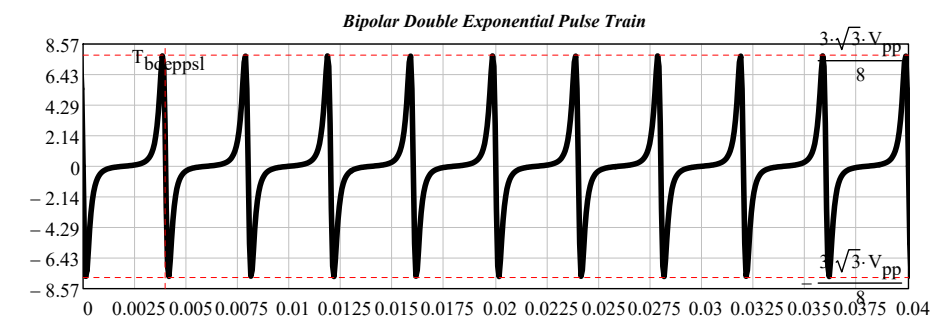
35 Agnesi Profile Voltage Pulse Train



TEST Waveforms

Periodic Waveforms

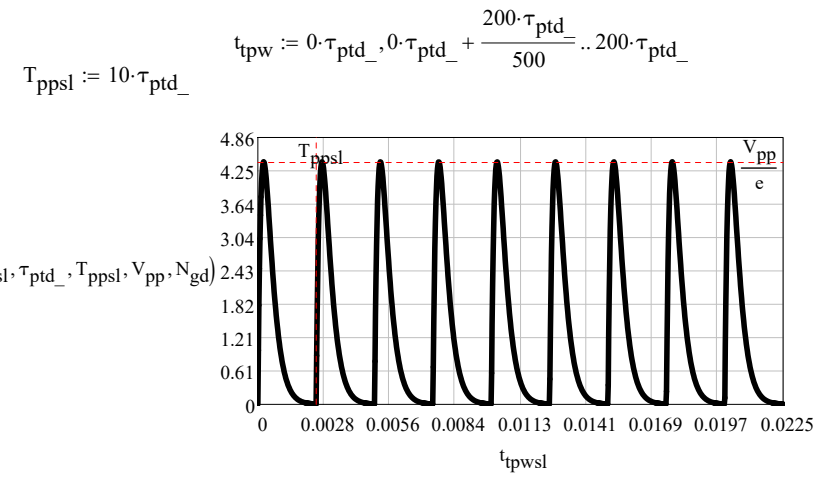
36 Agnesi Derivative Profile Voltage Pulse Train



TEST Waveforms

Periodic Waveforms

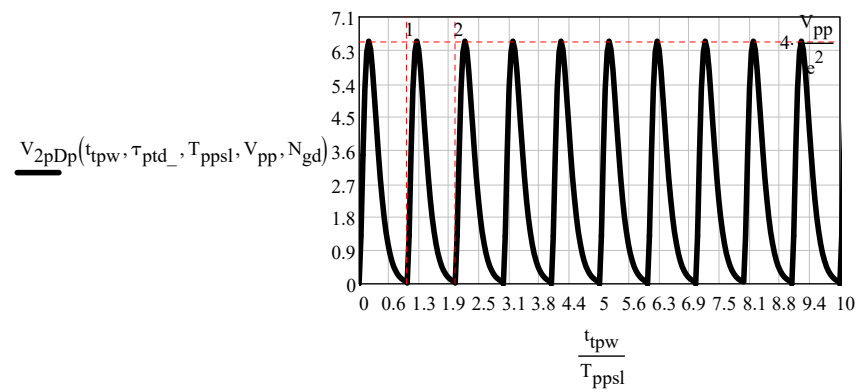
37 Poisson Profile Voltage Pulse Train



TEST Waveforms

Periodic Waveforms

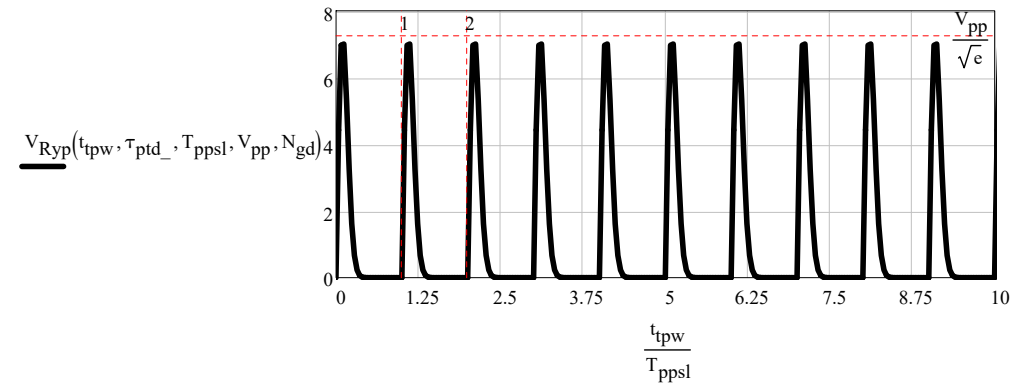
38 Poisson Derivative Profile Voltage Pulse Train



TEST Waveforms

Periodic Waveforms

39 Rayleigh Profile Voltage Pulse Train



TEST Waveforms

Periodic Waveforms

40 Cap. Charge and Discharge Pulse Train

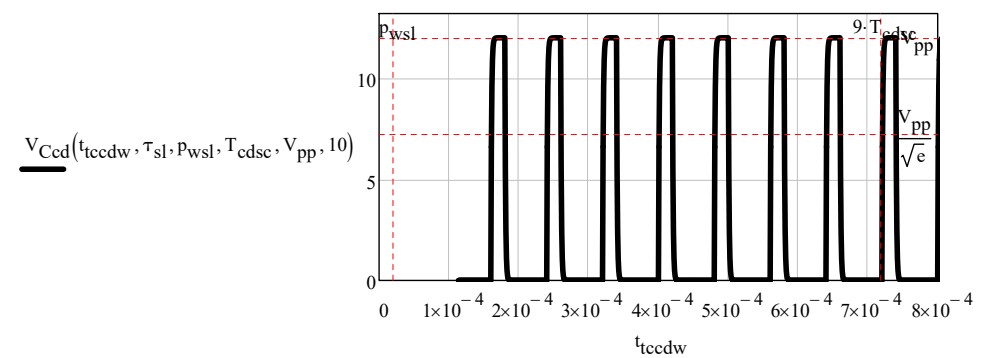
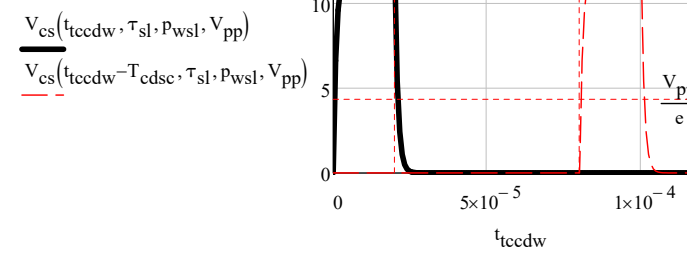
pulse width: $P_{wsl} := 20 \cdot \mu s$

time constant $\tau_{sl} := \frac{P_{wsl}}{20}$

Period: $T_{cdsc} := 4 \cdot P_{wsl}$

$$t_{tccd} := 0 \cdot T_{cdsc}, 0 \cdot T_{cdsc} + \frac{100 \cdot T_{cdsc}}{10000} \dots 100 \cdot T_{cdsc}$$

Cap. Voltage Charge and Discharge

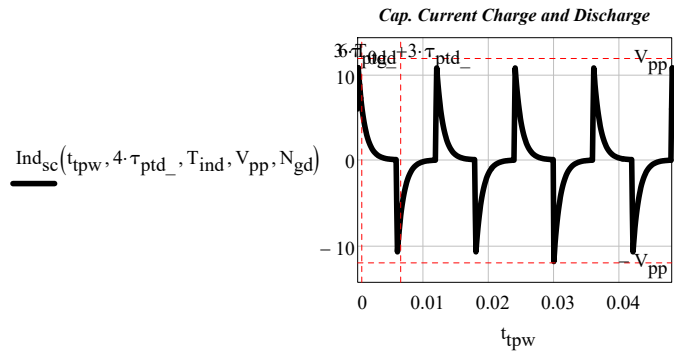


TEST Waveforms

Periodic Waveforms

41 Induct Charge and Discharge Pulse Train

$$T_{ind} := 6 \cdot T_{0gd}$$



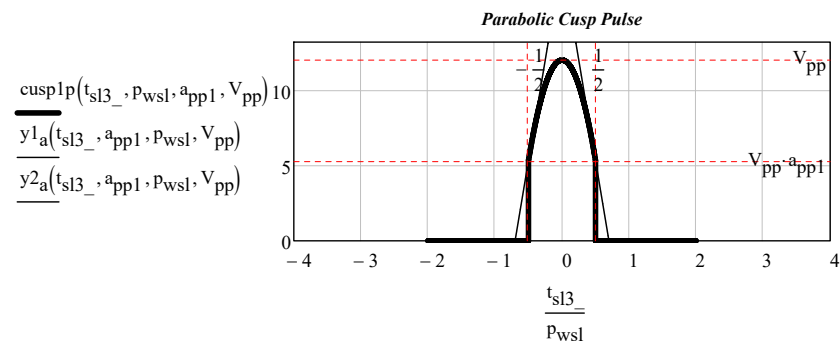
TEST Waveforms

Periodic Waveforms

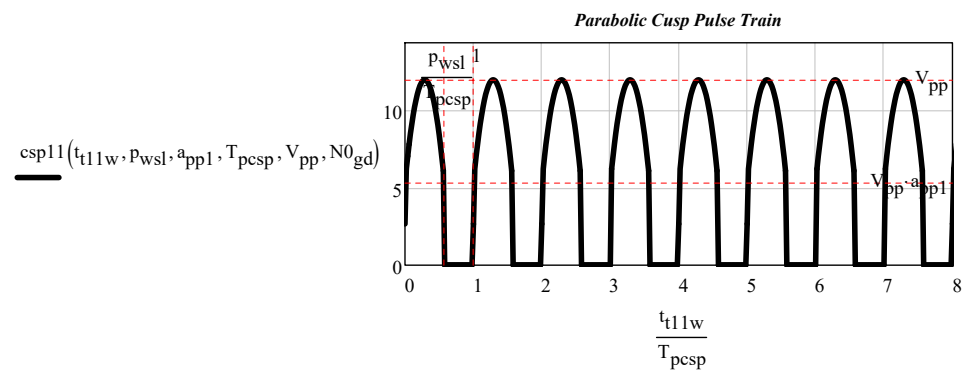
42 Parabolic Cusps Pulse Train

Signal amplitude: $V_{pp} = 12 \cdot V$
Pulse width: $P_{wsl} = 20 \cdot \mu s$
Duty cycle: $\delta_{cysl} := \gamma$
Period: $T_{pcsp} := \frac{P_{wsl}}{\delta_{cysl}}$
Max pulse amplitude and cusp ratio: $a_{pp1} := \frac{4}{9}$

$$t_{sl3_} := -2 \cdot P_{wsl}, -2 \cdot P_{wsl} + \frac{(2 \cdot P_{wsl} + 2 \cdot P_{wsl})}{10000} .. 2 \cdot P_{wsl}$$



$$t_{11w} := 0 \cdot T_{pcsp}, 0 \cdot T_{pcsp} + \frac{10 \cdot T_{pcsp} - 0 \cdot T_{pcsp}}{500} .. 10 \cdot T_{pcsp}$$



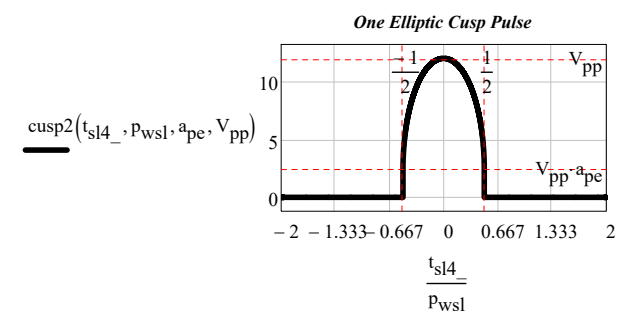
TEST Waveforms

Periodic Waveforms

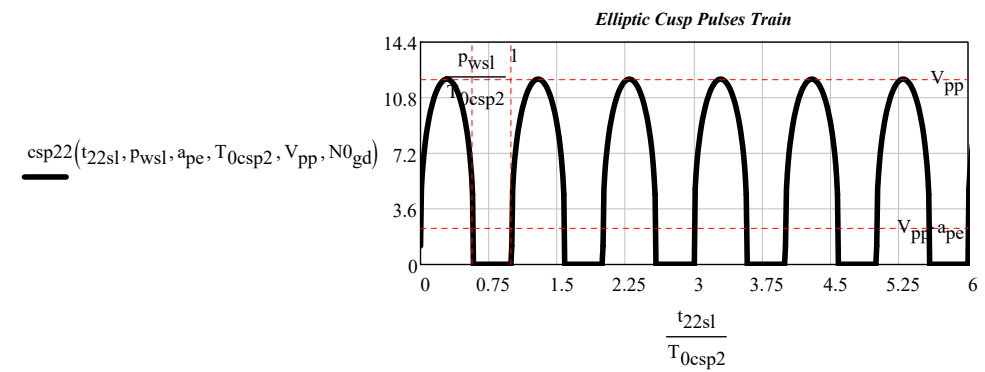
43 Elliptic Cusps Pulse Train

Signal amplitude: $V_{pp} = 12 \cdot V$
Pulse width: $P_{wsl} = 20 \cdot \mu s$
Duty cycle: $\delta_{cysl} := \gamma$
Period: $T_{0csp2} := \frac{P_{wsl}}{\delta_{cysl}}$
Max pulse amplitude and cusp ratio: $a_{pe} := \frac{2}{10}$

$$t_{sl4_} := -2 \cdot P_{wsl}, -2 \cdot P_{wsl} + \frac{(2 \cdot P_{wsl} + 2 \cdot P_{wsl})}{20000} .. 2 \cdot P_{wsl}$$



$$t_{22sl} := 0 \cdot T_{0csp2}, 0 \cdot T_{0csp2} + \frac{10 \cdot T_{0csp2} - 0 \cdot T_{0csp2}}{1000} .. 10 \cdot T_{0csp2}$$



Fine