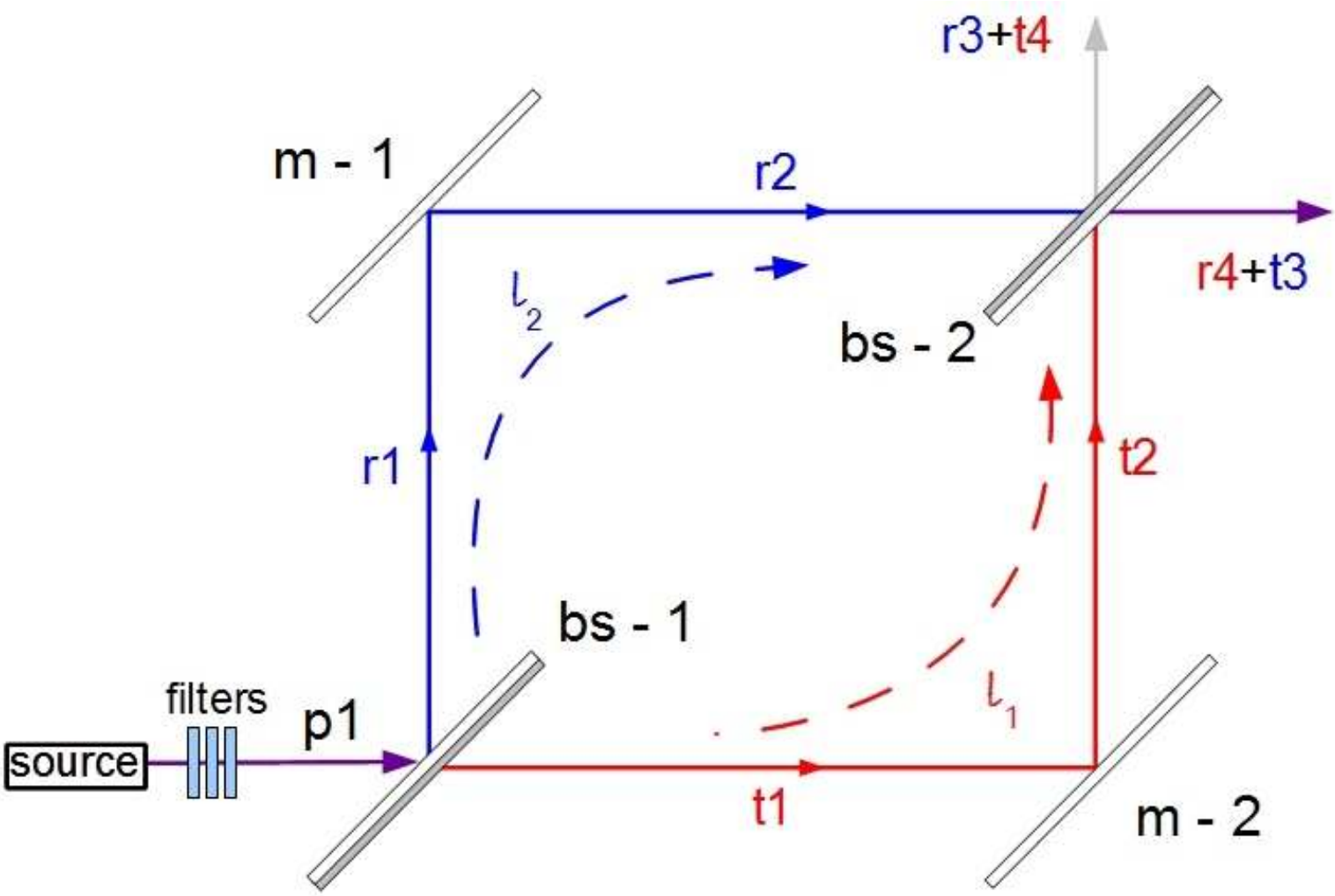
```
> restart;

> interface(warnlevel = 0) :          # Maple 12
> with(plots) :
```

Mach-Zehnder Interferometer w/ asymetrical beam splitter



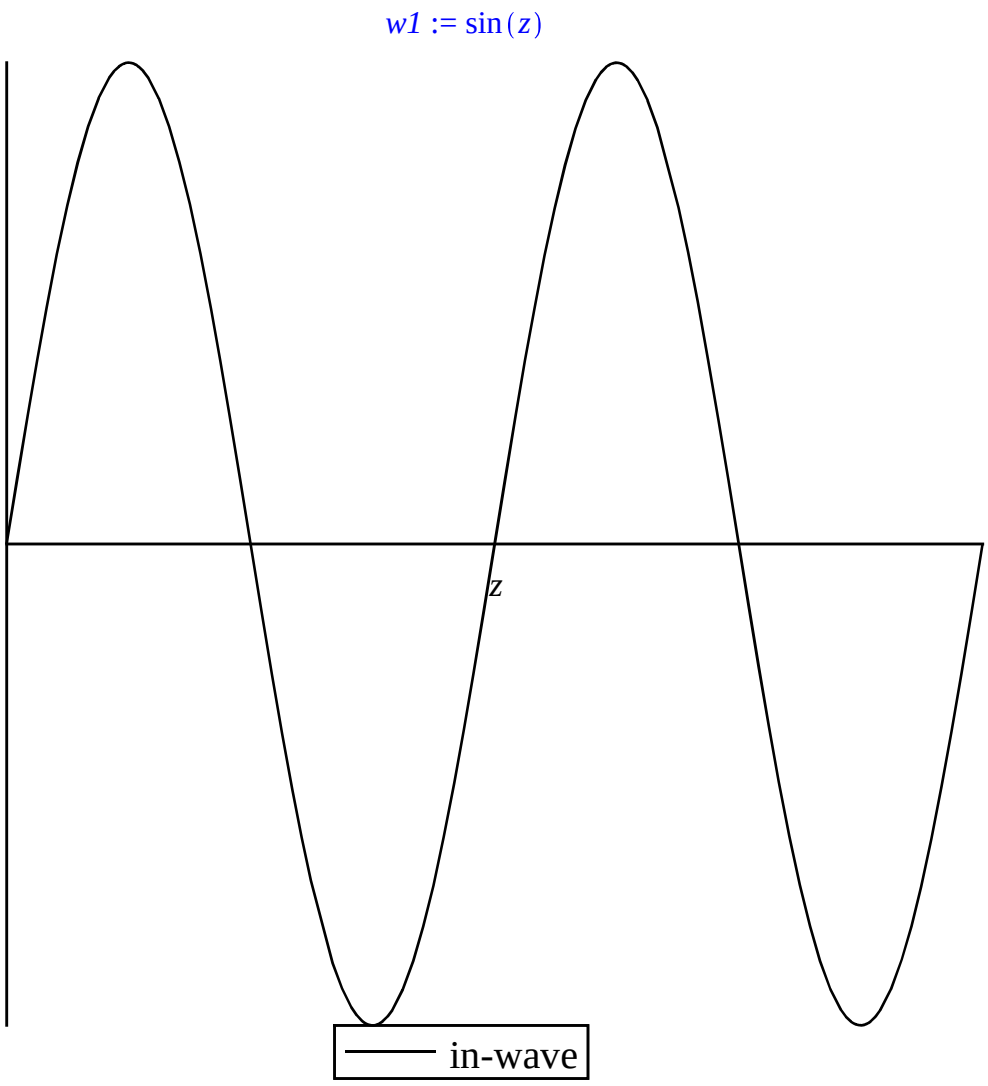
Incident beam w1

> $\varphi := -\frac{\pi}{2}$: # *initial phase*

A := 1 : # *initial amplitude*

w1 := *A* · *cos*(*z* + φ); # *incoming beam*

plot(*w1*, *z* = 0 ..4·π, *color* = *black*, *tickmarks* = [0, 0], *legend* = ["in-wave"]);



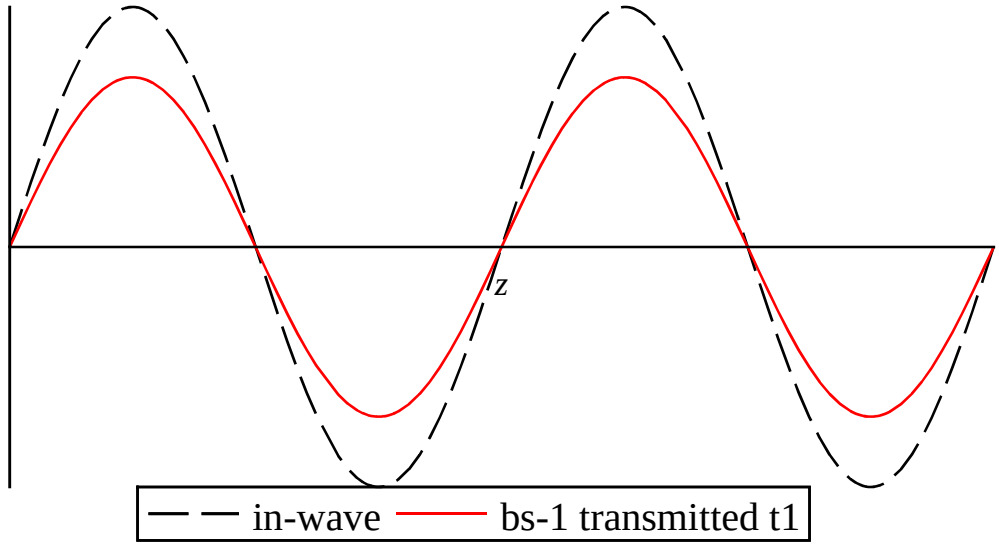
At the first beam splitter: transmitted beam t1 and reflected beam r1.
Also the amplitude of r1 and t1 satisfy the condition

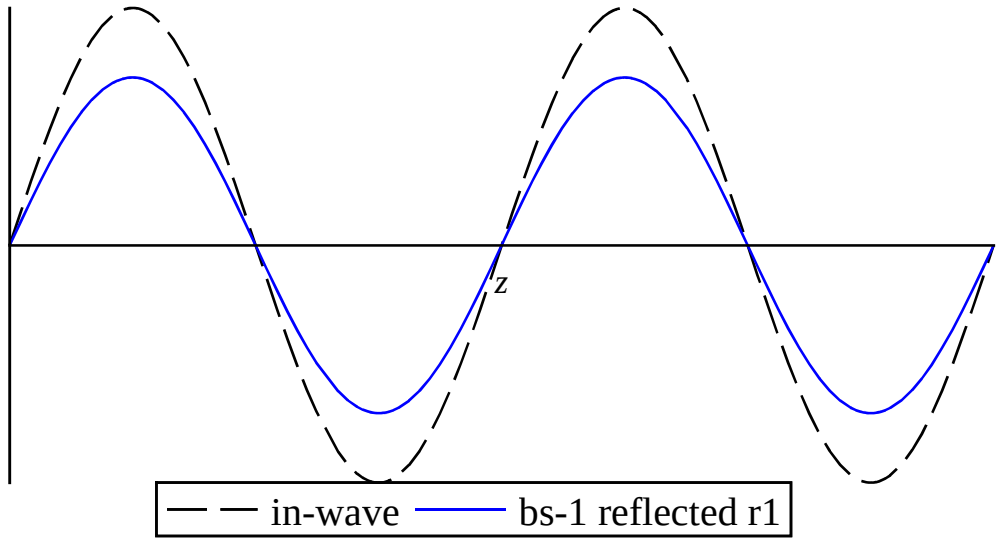
$$A1^2 + A1^2 = A^2$$

```
> φ1 := φ + 0 :  #` `phase of reflected r1
  φ2 := φ :        # phase of transmitted t1
  A1 := 1/sqrt(2) · A :  # amplitude of r1 and t1
  p1 := plot(w1, z = 0 ..4·π, color = black, linestyle = 3, tickmarks = [0, 0], legend = ["in-wave"]) :
  r1 := A1 · cos(z + φ1); t1 := A1 · cos(z + φ2);
  pr1 := plot(r1, z = 0 ..4·π, color = blue, tickmarks = [0, 0], legend = ["bs-1 reflected r1"]) :
  pt1 := plot(t1, z = 0 ..4· π, color = red, tickmarks = [0, 0], legend = ["bs-1 transmitted t1"]) :
  display([p1, pt1]); display([p1, pr1]);
```

$$r1 := \frac{1}{2}\sqrt{2}\,\sin(z)$$

$$t1 := \frac{1}{2}\sqrt{2}\,\sin(z)$$

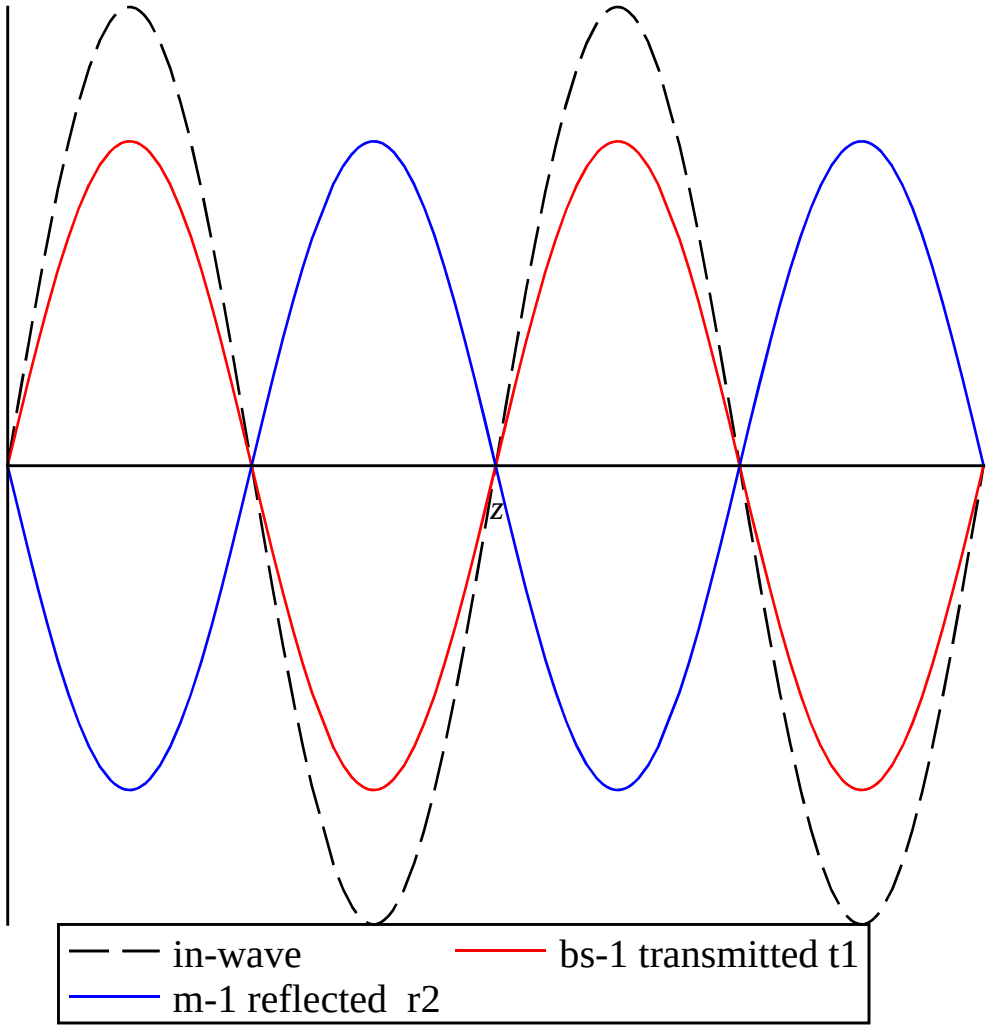




At mirror 1, m-1, r1 phase shifts by 180 degrees

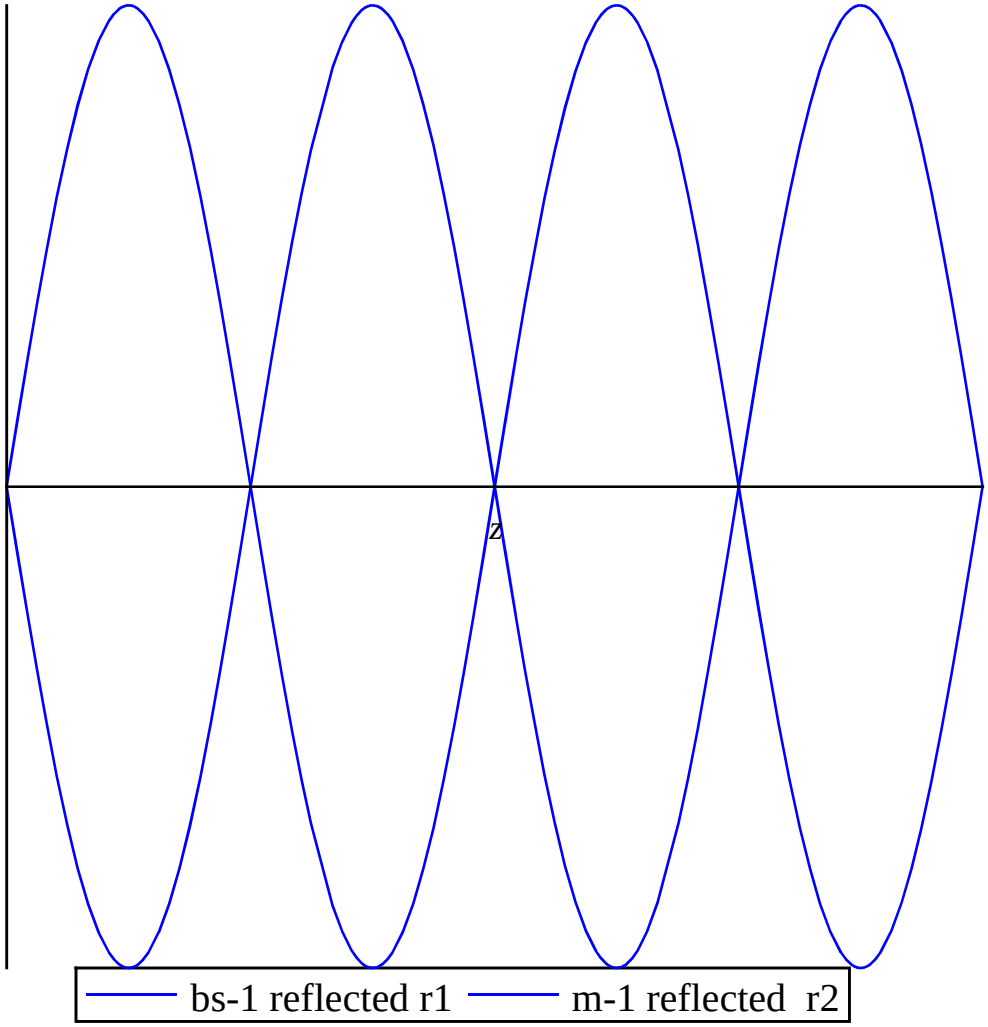
```
> φ1 := φ1 + π :  #` `reflected  r2
  r2 := A1 · cos(z + φ1); # reflected  r2
  pr2 := plot( r2, z = 0 ..4· π, color = blue, tickmarks = [0, 0], legend = ["m-1 reflected  r2"]) :
  display( [p1, pt1, pr2]);
```

$$r2 := -\frac{1}{2}\sqrt{2}\,\sin(z)$$



r1 and r2 are 180 degrees out of phase as expected

```
> display([pr1, pr2]);
```

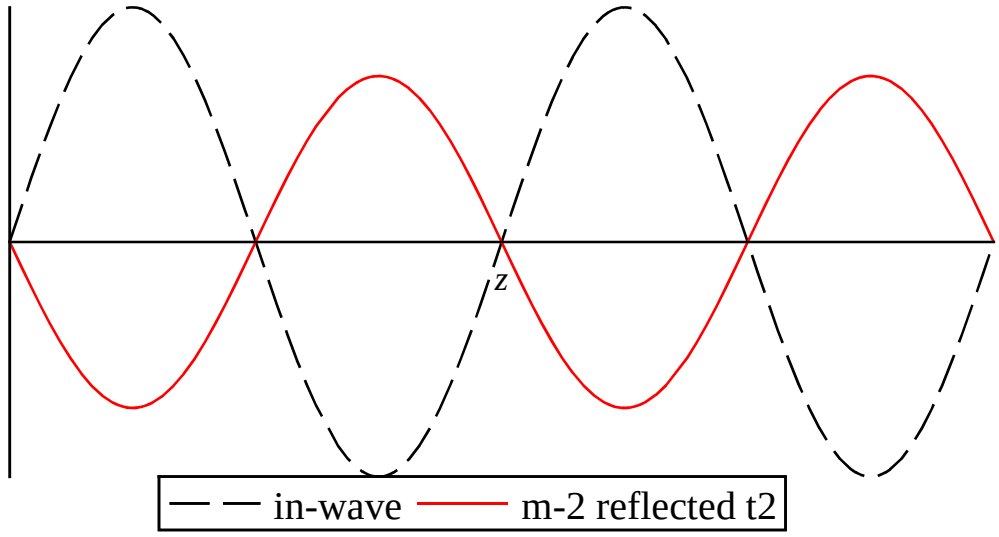


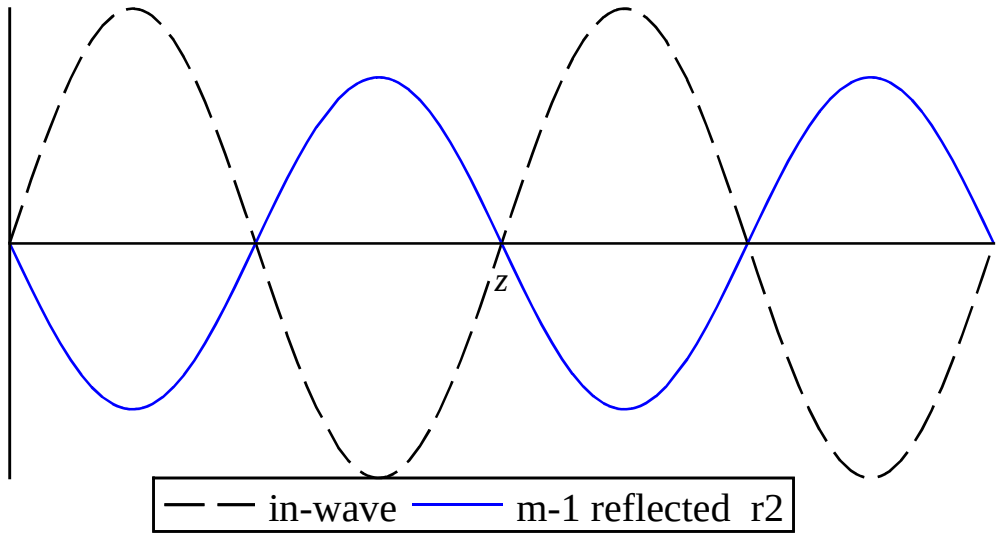
At mirror 2, m-2, t2 phase shifts by 180 degrees

```
> φ2 := φ2 + π :
  t2 := A1· cos(z + φ2); # reflected t2
  Δ := φ1 − φ2; # phase difference between r2 and t2
  pt2 := plot(t2, z = 0..4· π, color = red, tickmarks = [0, 0], legend = ["m-2 reflected t2"]) :
  display([p1, pt2]); display([p1, pr2]);
```

$$t2 := -\frac{1}{2}\sqrt{2}\,\sin(z)$$

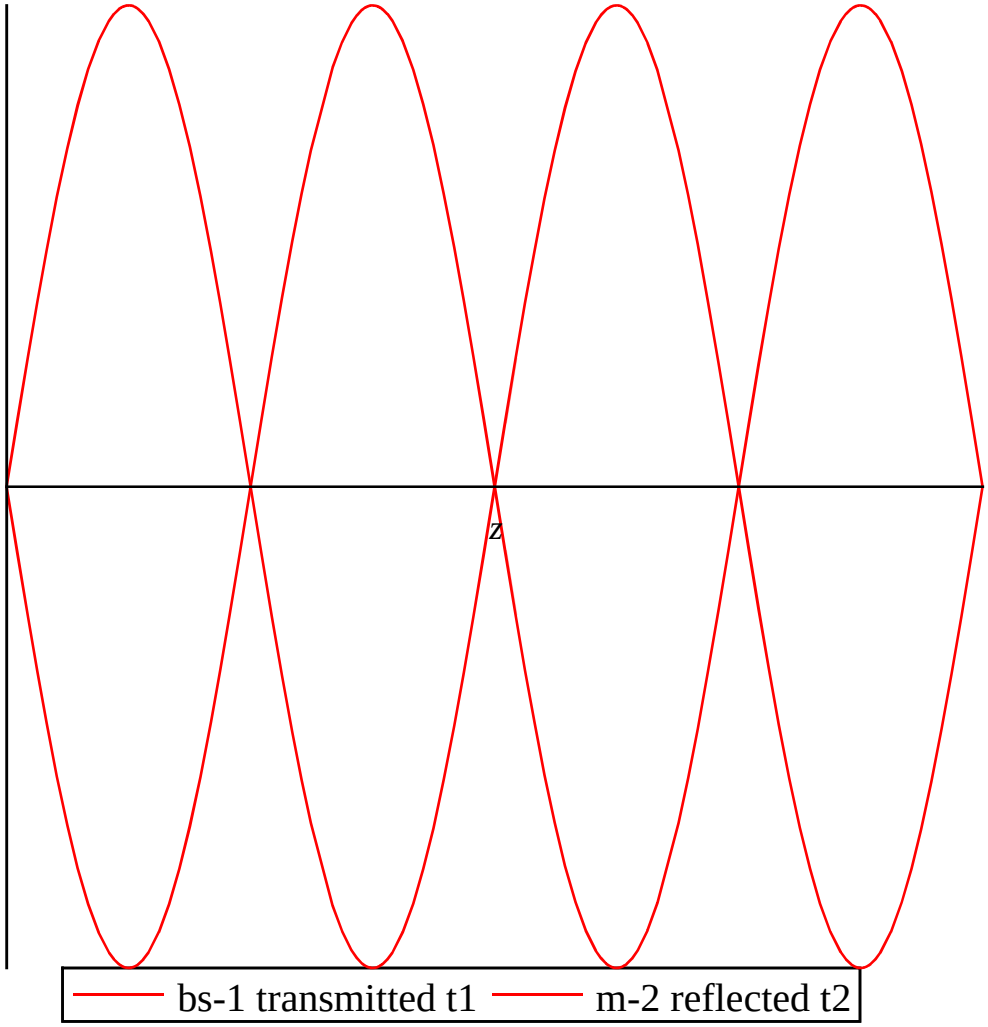
$$\Delta := 0$$





t2 and t1 are 180 degrees out of phase as expected

```
> display([pt1, pt2]);
```



At beam splitter 2, r2 is split into transmitted t3 and reflected r3 and t2 is split into a transmitted t4 and reflected wave r4.

> $t3 := \frac{r2}{\sqrt{2}};$

$t4 := \frac{t2}{\sqrt{2}};$

$pt4 := plot(t4, z = 0..4\cdot\pi, color = red, tickmarks = [0, 0], legend = ["bs-2 transmitted t4"]):$

$pt3 := plot(t3, z = 0..4\cdot\pi, color = blue, tickmarks = [0, 0], legend = ["bs-2 transmitted t3"]):$

$pt2 := plot(t2, z = 0..4\cdot\pi, color = coral, linestyle = 3, tickmarks = [0, 0], legend = ["m-2 reflected t2"]):$

$pr2 := plot(r2, z = 0..4\cdot\pi, color = cyan, linestyle = 3, tickmarks = [0, 0], legend = ["m-1 reflected r2"]):$

$\varphi 1 := \varphi 1 - \pi : r2 := A1\cdot cos(z + \varphi 1):$

$r3 := \frac{1}{\sqrt{2}}\cdot r2;$

$\varphi 2 := \varphi 2 + 0 : t2 := A1\cdot cos(z + \varphi 2):$

$r4 := \frac{1}{\sqrt{2}}\cdot t2;$

$pr4 := plot(r4, z = 0..4\cdot\pi, color = blue, tickmarks = [0, 0], legend = ["bs-2 reflcted r4"]):$

$pr3 := plot(r3, z = 0..4\cdot\pi, color = red, tickmarks = [0, 0], legend = ["bs-2 reflected r3"]):$

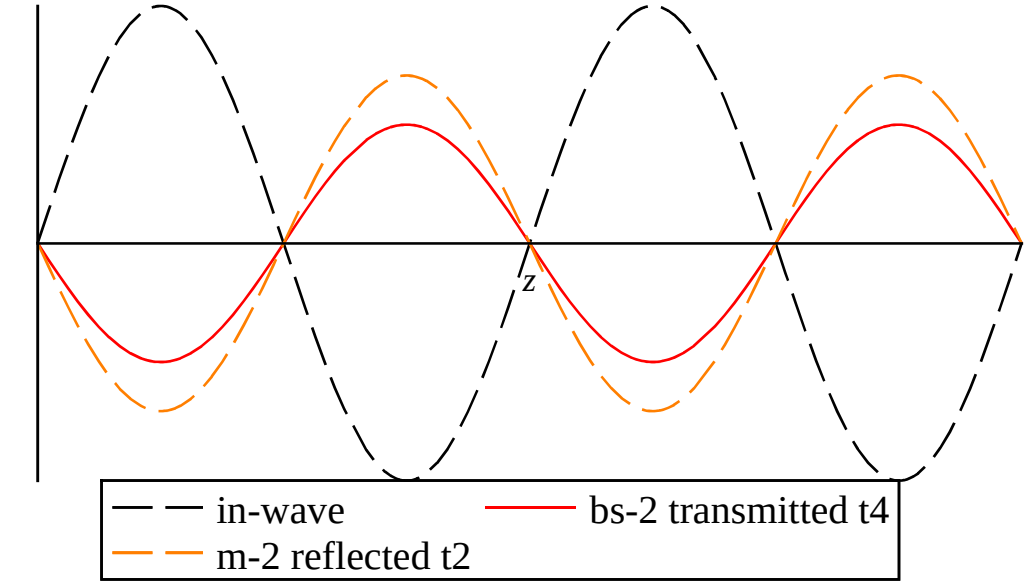
$display([p1, pt4, pt2]); display([p1, pt3, pr3, pr2]); display([p1, pr4, pt2]);$

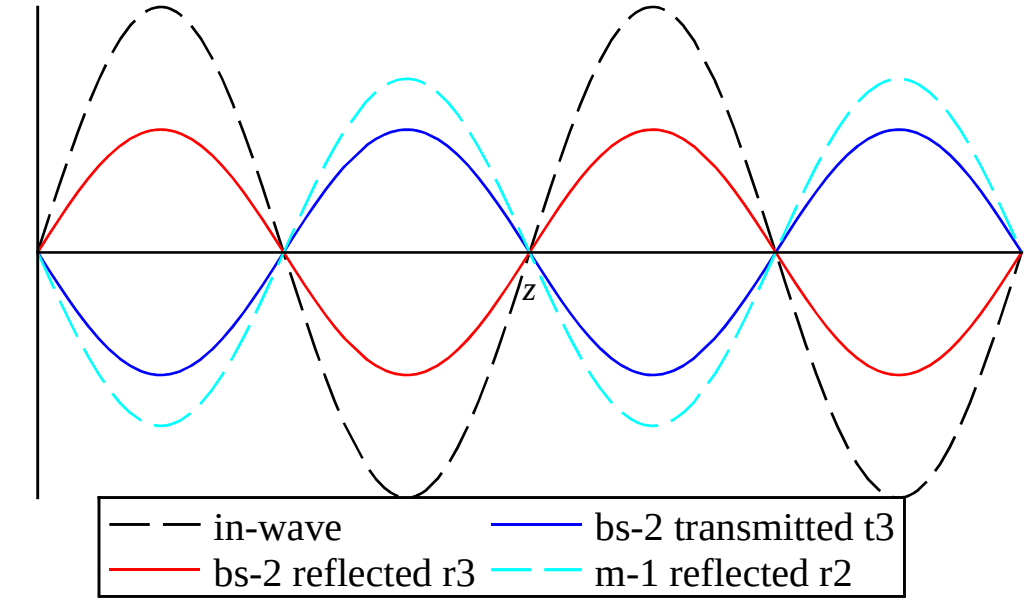
$$t3 := -\frac{1}{2}\sin(z)$$

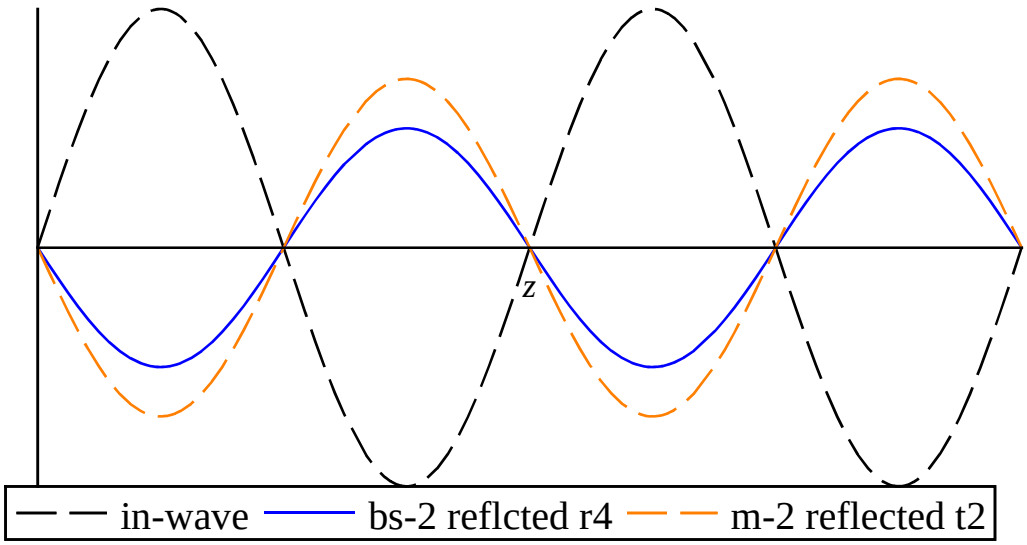
$$t4 := -\frac{1}{2}\sin(z)$$

$$r3 := \frac{1}{2}\sin(z)$$

$$r4 := -\frac{1}{2}\sin(z)$$


z
in-wave
bs-2 transmitted t4
m-2 reflected t2


z
in-wave
bs-2 transmitted t3
bs-2 reflected r3
m-1 reflected r2


z
in-wave
bs-2 reflcted r4
m-2 reflected t2

```
> 'w1'= w1;
  D1 := (r4 + t3) : 'r4 + t3' = D1;
  D2 := (r3 + t4) : 'r3 + t4' = D2;
  pD1 := plot(D1, z = 0..4· π, color = blue, thickness = 2, tickmarks = [0, 0], legend = ["r4+t3"]) :
  pD2 := plot(D2, z = 0..4· π, color = red, thickness = 2, tickmarks = [0, 0], legend = ["r3+t4"]) :
  display([p1, pD1, pD2], title = ["\n 180 degrees phase shift\n"], font = [times, bold, 14]);
```

$$w1 = \sin(z)$$

$$r4 + t3 = -\sin(z)$$

$$r3 + t4 = 0$$