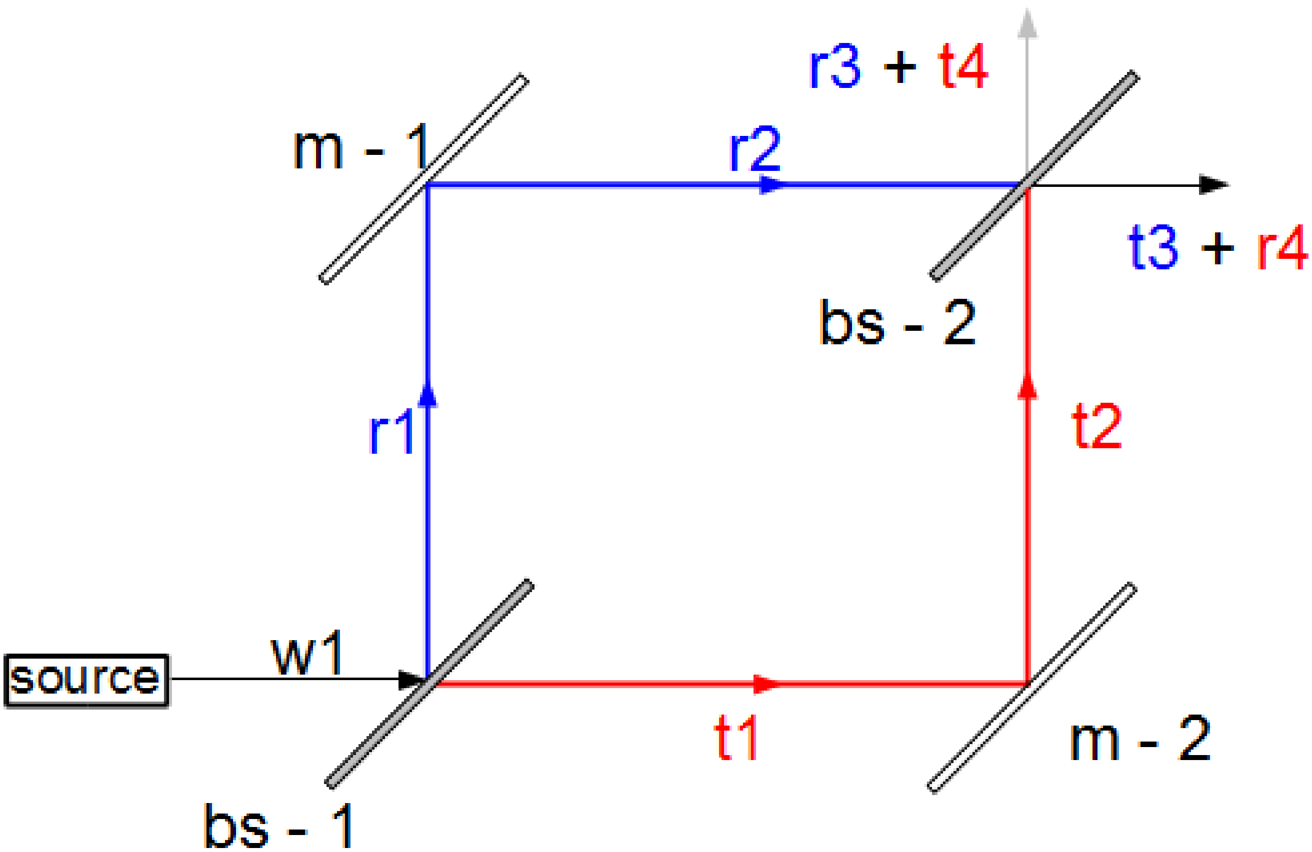
```
> restart;
> interface(warnlevel = 0) :            # Maple 12
> with(plots) :
```

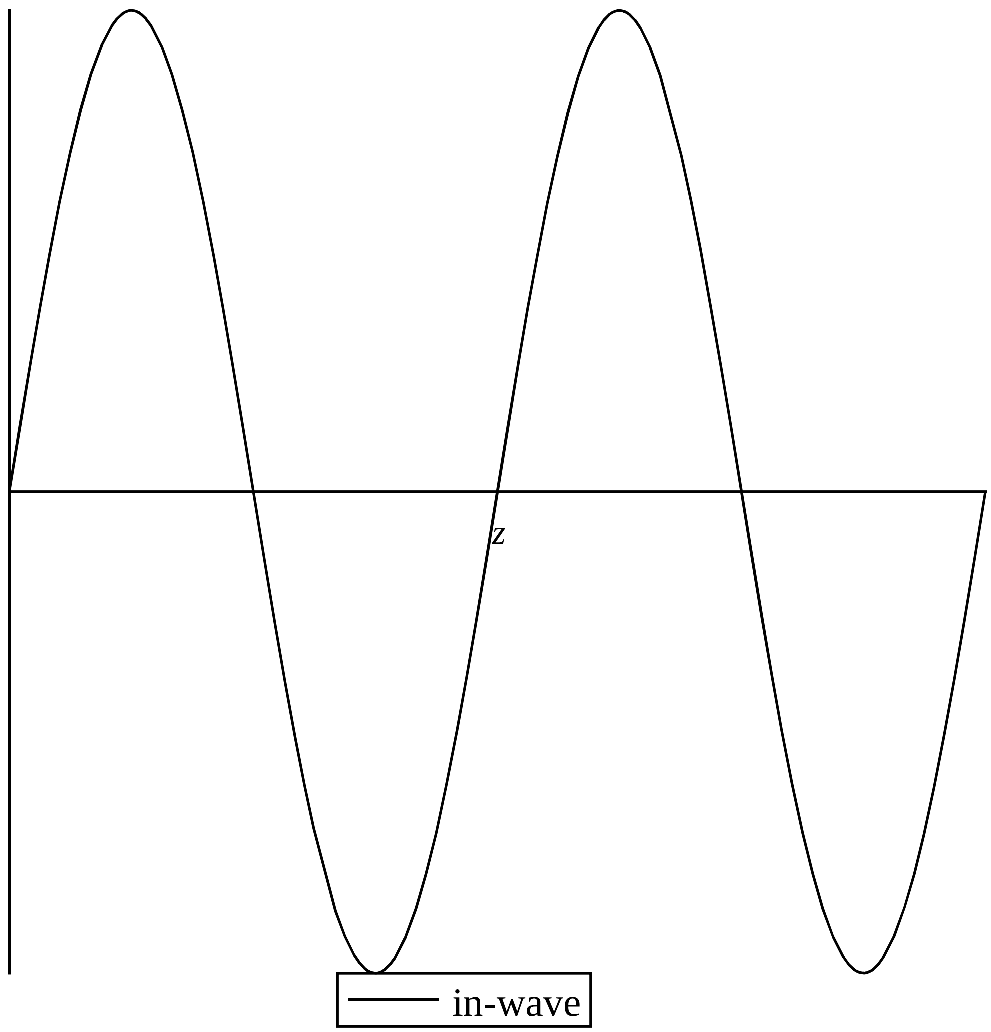
Assume that we have totally reflecting mirrors and 50:50 symmetric beam splitters



Incident beam w1

> $\varphi := -\frac{\pi}{2}$: # *initial phase*
$A := 1$: # *initial amplitude*
$w1 := A \cdot \cos(z + \varphi)$; # *incoming beam*
$plot\left(w1, z = 0 .. 4 \cdot \pi, color = black, tickmarks = [0, 0], legend = [\text{"in-wave"}]\right)$;

$$w1 := \sin(z)$$



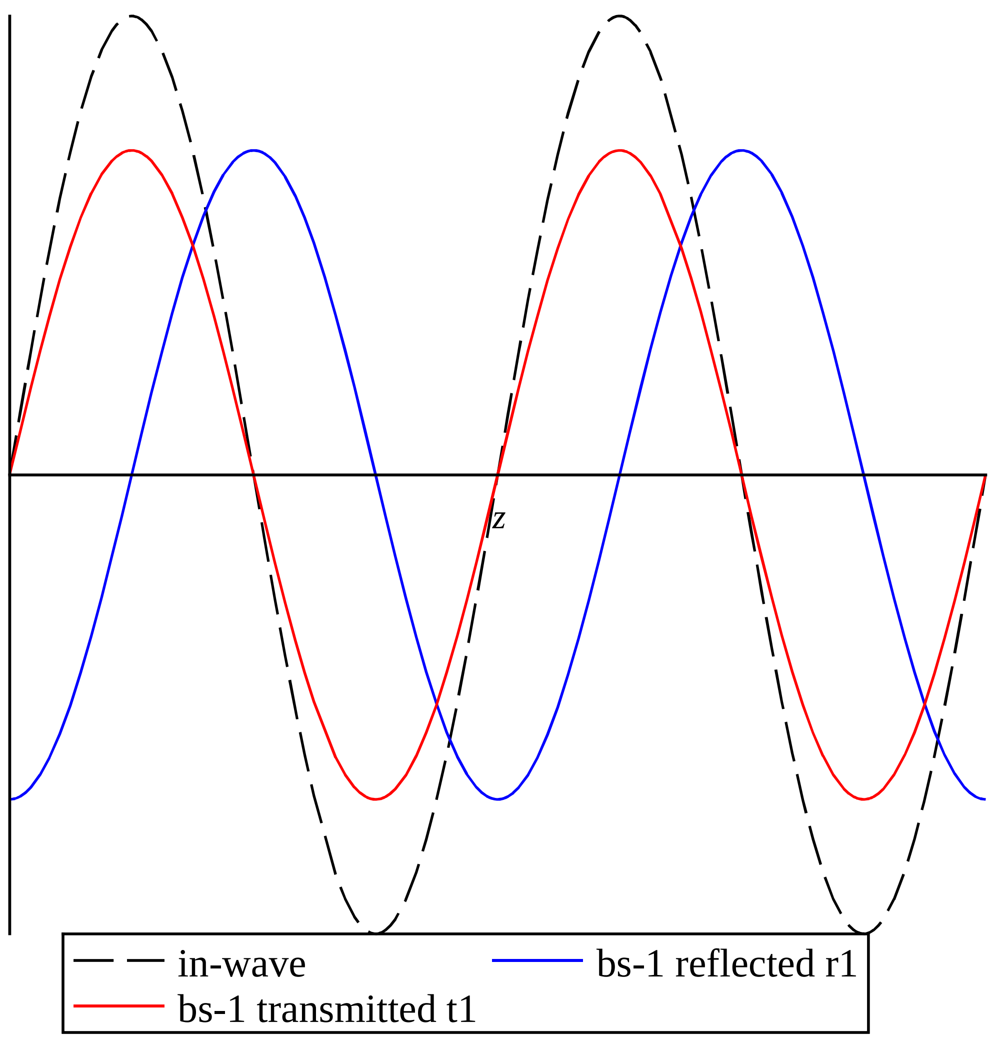
At the first beam splitter: transmitted beam t1 and reflected beam r1.
Also the amplitude of r1 and t1 satisfy the condition

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

> $\varphi 1 := \varphi - \frac{\pi}{2}$: # *phase of reflected r1*
$\varphi 2 := \varphi$:   # *phase of transmitted t1*
$A1 := \frac{1}{\sqrt{2}} \cdot A$: # *amplitude of r1 and t1*
$p1 :=$ plot(w1, z = 0 ..4·π, color = black, linestyle = 3, tickmarks = [0, 0], legend = ["in-wave"]) :
$r1 := A1 \cdot \cos(z + \varphi 1)$;
$t1 := A1 \cdot \cos(z + \varphi 2)$;
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, pr1, pt1]);

$$r1 := -\frac{1}{2}\sqrt{2}\cos(z)$$

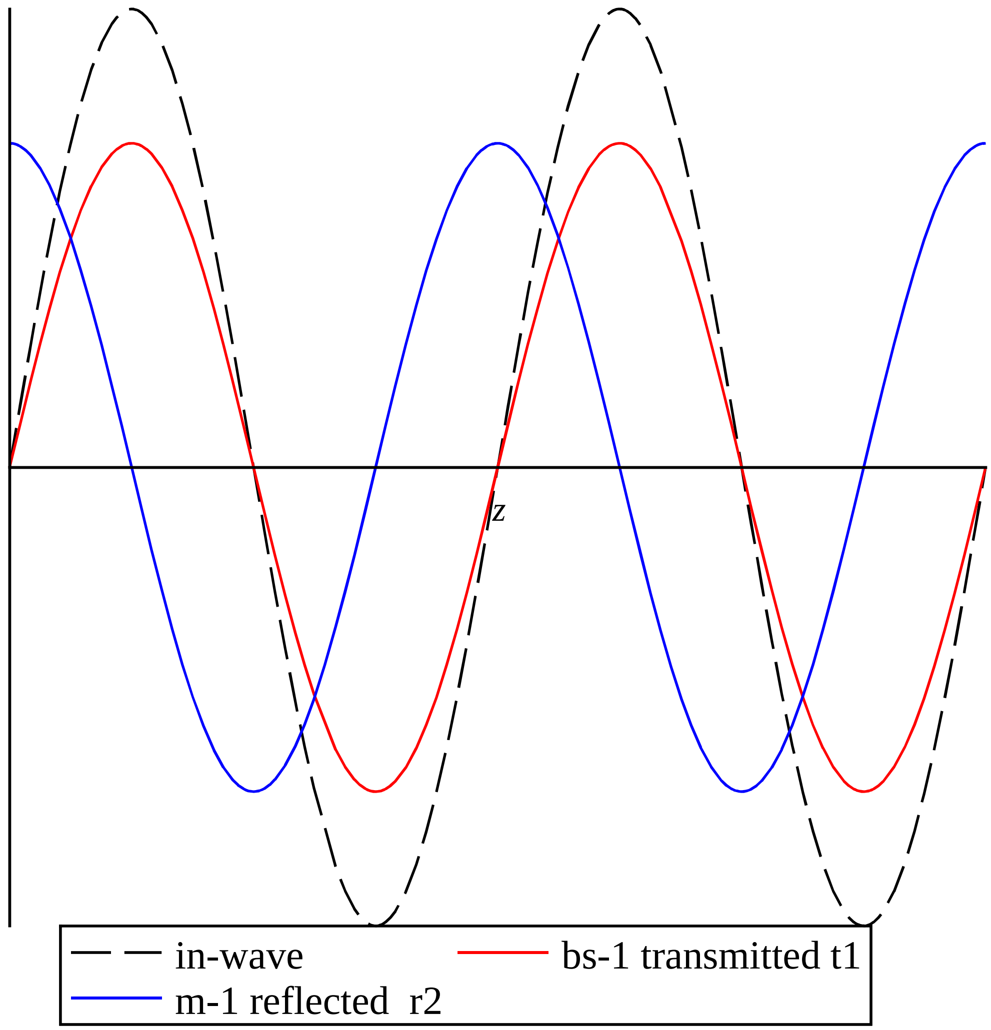
$$t1 := \frac{1}{2}\sqrt{2}\sin(z)$$



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

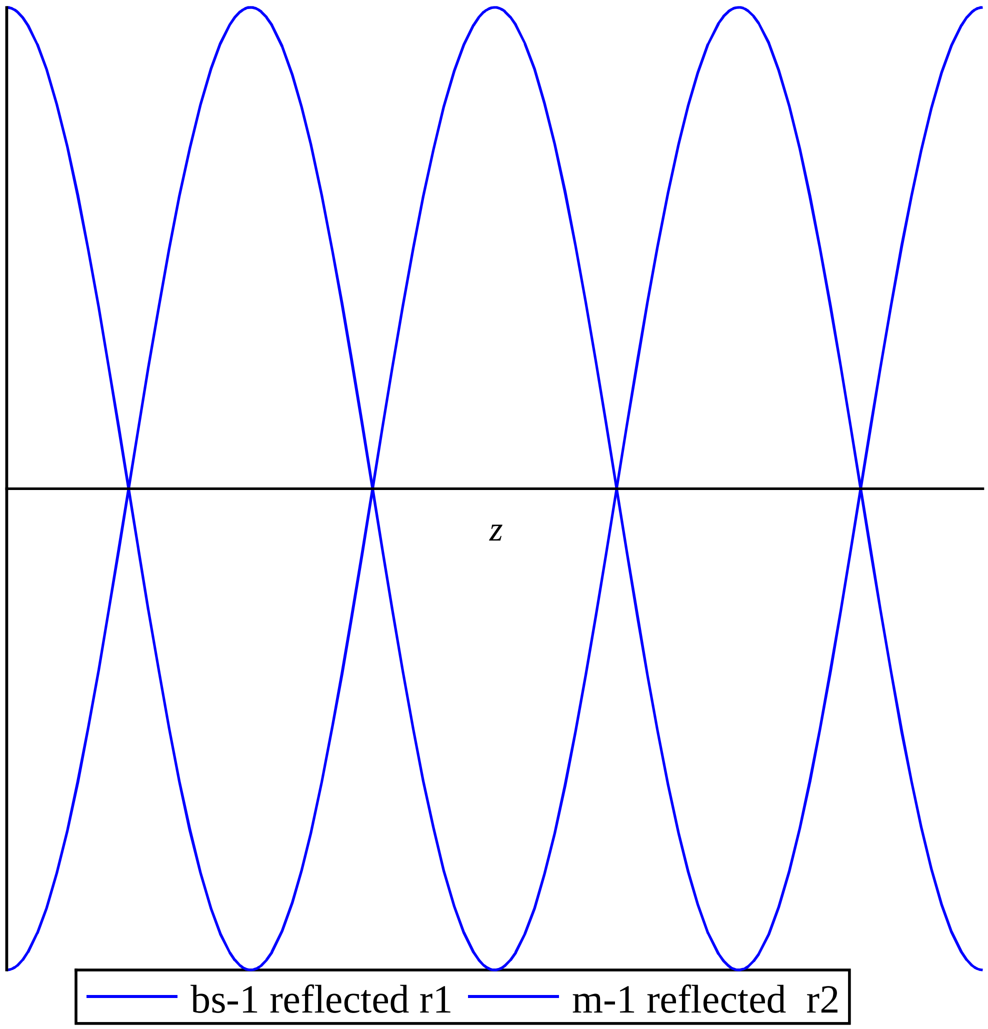
> $\varphi 1 := \varphi 1 + \pi$: #` `*reflected r2*
> $r2 := A1 \cdot \cos(z + \varphi 1)$; # *reflected r2*
> $pr2 := plot\left(r2, z = 0 ..4 \cdot \pi, color = blue, tickmarks = [0, 0], legend = [\text{"m-1 reflected r2"}]\right)$:
> $display([p1, pt1, pr2])$;

$$r2 := \frac{1}{2}\sqrt{2}\cos(z)$$



r1 and r2 are 180 degrees out of phase as expected

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

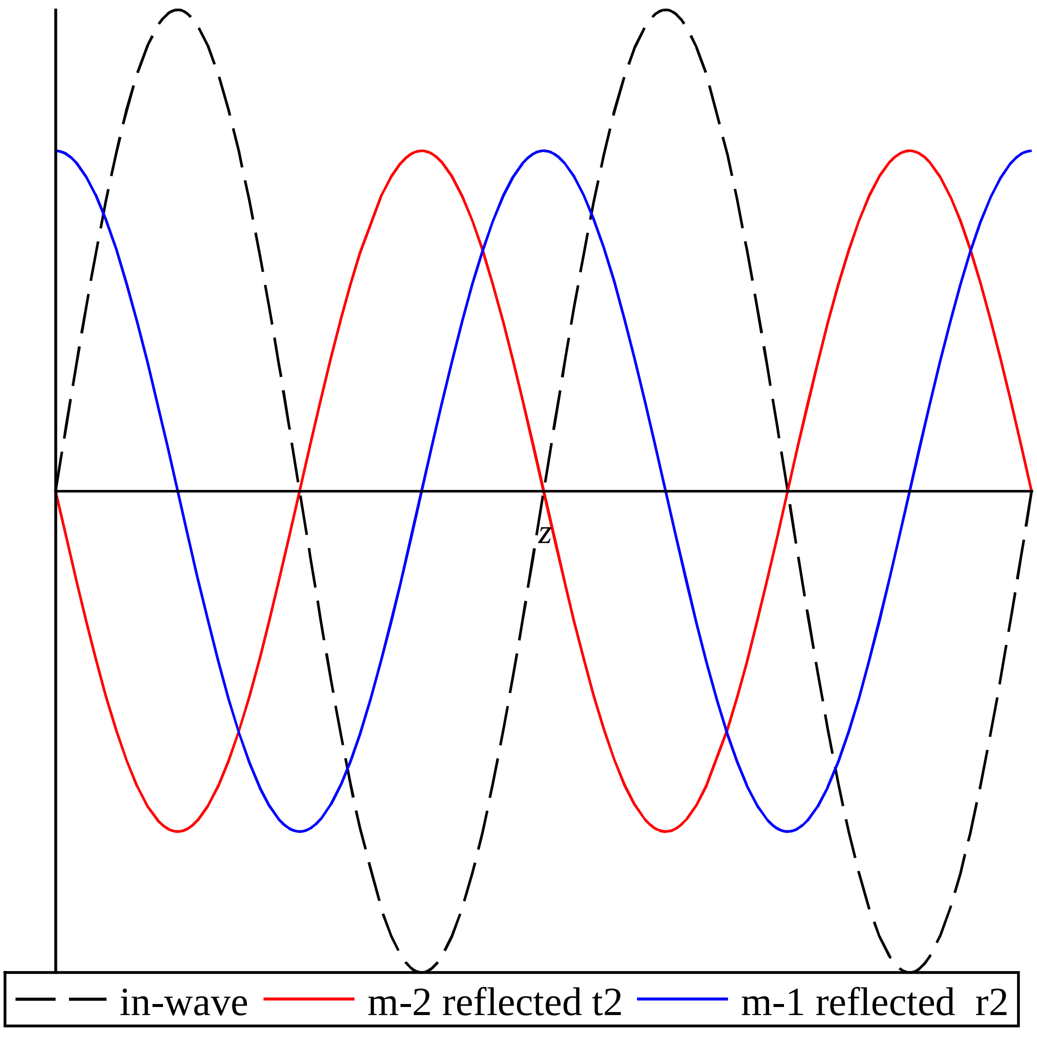


At mirror 2, m-2, t2 phase shifts by 180 degrees

$>$ $\varphi 2 := \varphi 2 + \pi :$
$t2 := A1 \cdot \cos(z + \varphi 2);$ # *reflected t2*
$\Delta := \varphi 1 - \varphi 2;$ # *phase difference between r2 and t2*
$pt2 := plot(t2, z = 0..4 \cdot \pi, color = red, tickmarks = [0, 0], legend = ["\text{m-2 reflected t2}"]) :$
$display([p1, pt2, pr2]);$

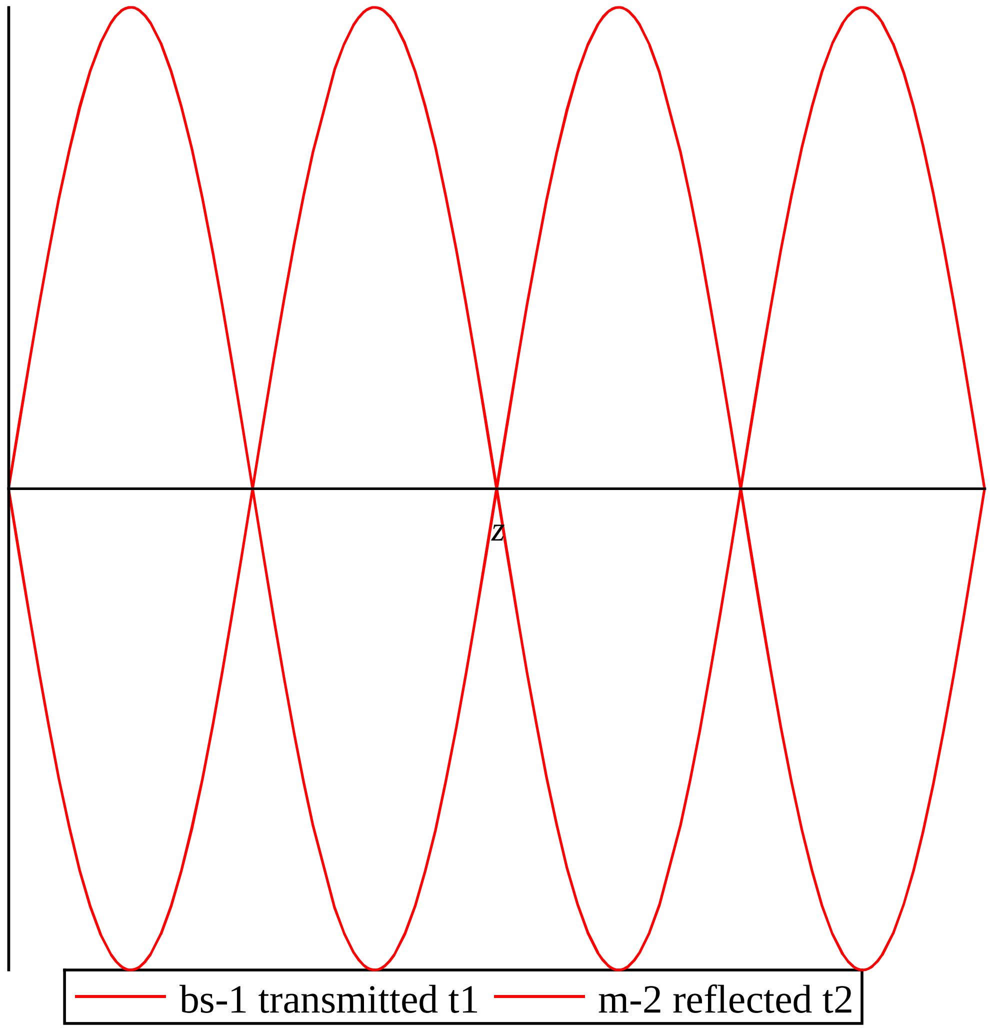
$$t2 := -\frac{1}{2}\sqrt{2}\,\sin(z)$$

$$\Delta := -\frac{1}{2}\pi$$



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"$]) :$

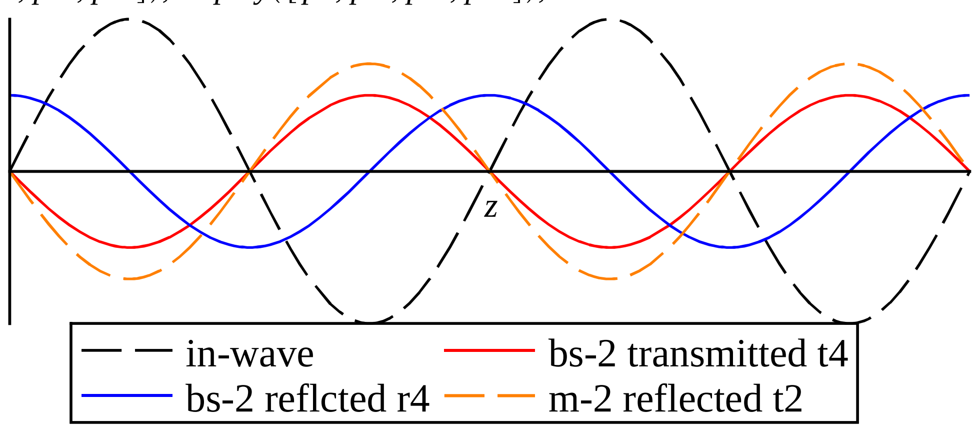
$\varphi1 := \varphi1 - \frac{\pi}{2} : r2 := A1 \cdot cos(z + \varphi1) : r3 := \frac{1}{\sqrt{2}} \cdot r2 : \varphi2 := \varphi2 - \frac{\pi}{2} : t2 := A1 \cdot cos(z + \varphi2) :$

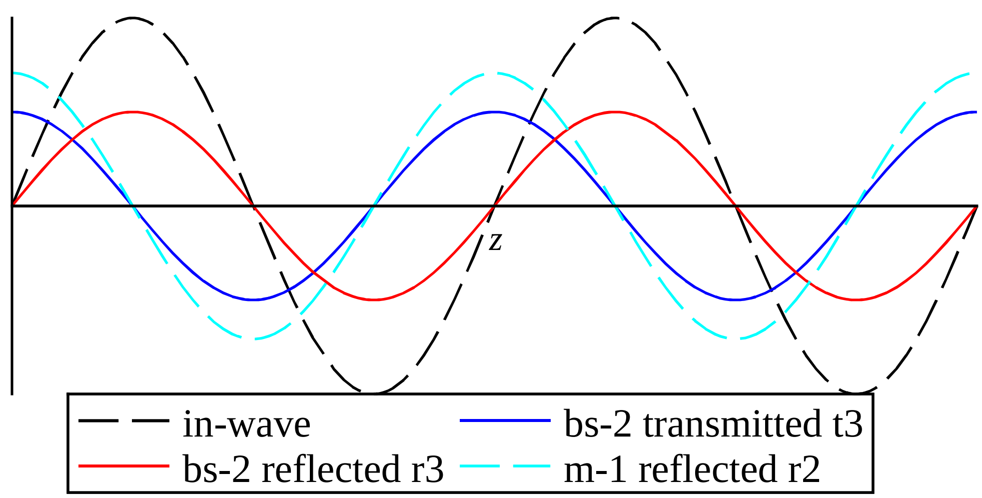
$r4 := \frac{1}{\sqrt{2}} \cdot t2 :$

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

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

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





Detectors

```
> D1 := (r4 + t3) : 'r4 + t3' = D1;
D2 := (r3 + t4) : 'r3 + t4' = D2;
pD1 := plot(D1, z = 0 ..4·π, color = "Purple", thickness = 2, tickmarks = [0, 0],  legend = ["r4+t3"]) :
pD2 := plot(D2, z = 0 ..4·π, color = "Salmon", thickness = 4, tickmarks = [0, 0], legend = ["r3+t4"]) :
display( [p1, pD1, pD2], title = ["\n90 degrees phase shift\n"], font = [times, bold, 14]);
```

$$r4 + t3 = \cos(z)$$
$$r3 + t4 = 0$$