

Analyze Märklin track signal

Get MM2 signal from track

Load files

```
In[1]:= Directory[]  
Out[1]= /home/cmaier/scad/Märklin/analysis  
  
In[2]:= Dimensions[raw = Import["MM2.78.run*.csv"]]  
Out[2]= {2, 1048578, 3}  
  
In[3]:= Take[#, 4] & /@ raw  
Out[3]= {{X, CH1, }, {Second, Volt, }, {-0.231344, -17.2, }, {-0.231343, -17.2, }},  
{{X, CH1, }, {Second, Volt, }, {-0.232, -17.2, }, {-0.231999, -17.2, }}}
```

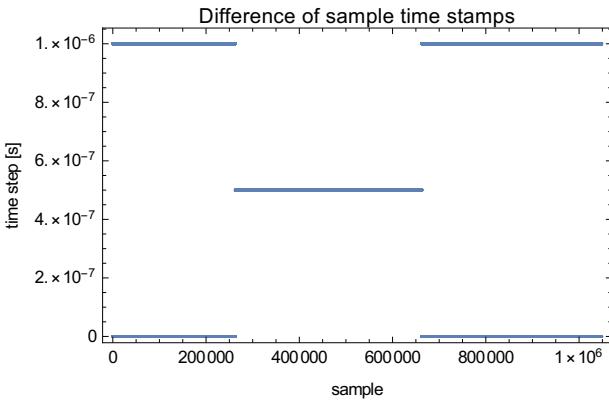
Convert into time series

```
In[4]:= Dimensions[timeseries = Most /@ Drop[#, 2] & /@ raw]  
Out[4]= {2, 1048576, 2}
```

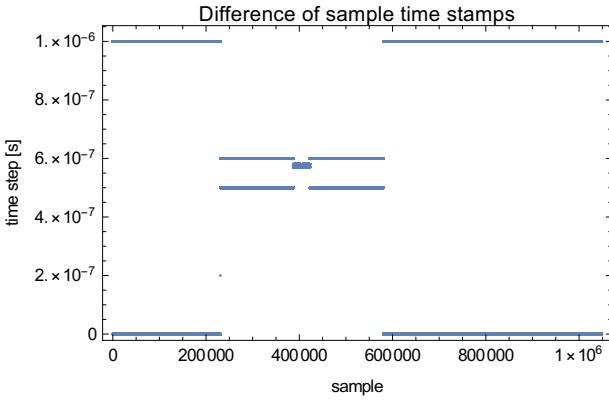
Calculate time step

```
In[5]:= Dimensions[ListConvolve[{1, -1}, First /@ #] & /@ timeseries]  
Out[5]= {2, 1048575}
```

```
In[6]:= GraphicsGrid[
{ListPlot[ListConvolve[{1, -1}, First /@ #], Frame → True, PlotRange → All,
FrameLabel → {"sample", "time step [s]"}, PlotLabel → "Difference of sample time stamps"]} & /@ timeseries]
```



Out[6]=



In[7]:= {Min[#], Max[#]} & [ListConvolve[{1, -1}, First /@ #]] & /@ timeseries

Out[7]= {{0., 1. x 10^-6}, {0., 1. x 10^-6}}

In[8]:= Median[ListConvolve[{1, -1}, First /@ #]] & /@ timeseries

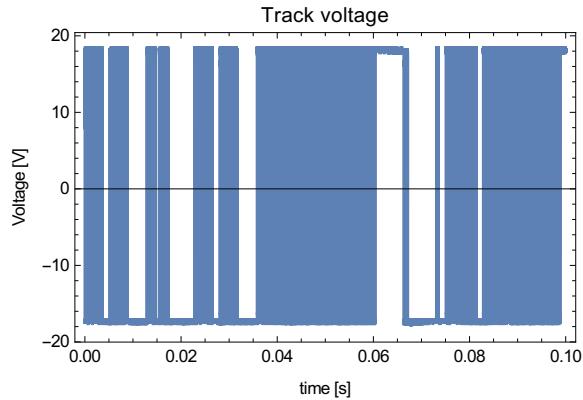
timestep = Round[First[%], 10^-9]

Out[8]= {5. x 10^-7, 6. x 10^-7}

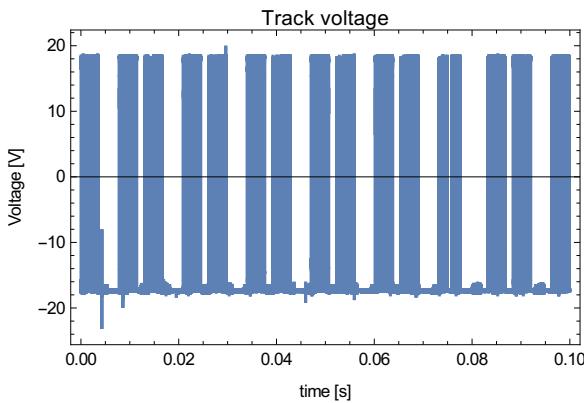
Out[9]= $\frac{1}{2\ 000\ 000}$

Display

```
In[10]:= GraphicsGrid[
{ListPlot[Select[#, 0 <= First[#] <=.1 &], Frame -> True, Joined -> True, FrameLabel ->
 {"time [s]", "Voltage [V]"}, PlotLabel -> "Track voltage"]}] &/@timeseries]
```



Out[10]=



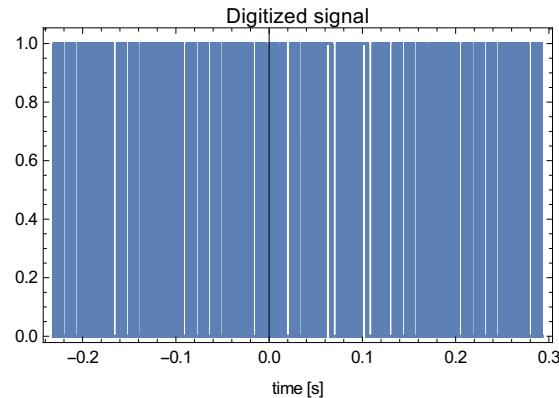
Digitize time series

```
In[11]:= Dimensions[digitized = Map[{#[[1]], HeavisideTheta[#[[2]] - 0.0001]} &, timeseries, {2}]]
```

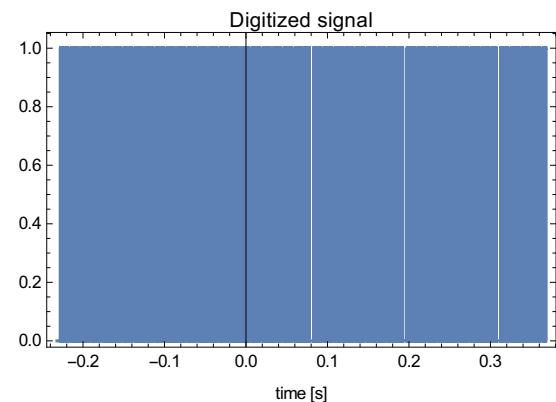
```
Out[11]= {2, 1048576, 2}
```

Display

```
In[12]:= GraphicsGrid[{ListPlot[#, Frame -> True, Joined -> True,
FrameLabel -> {"time [s]", ""}, PlotLabel -> "Digitized signal"]}] &/@digitized]
```



```
Out[12]=
```

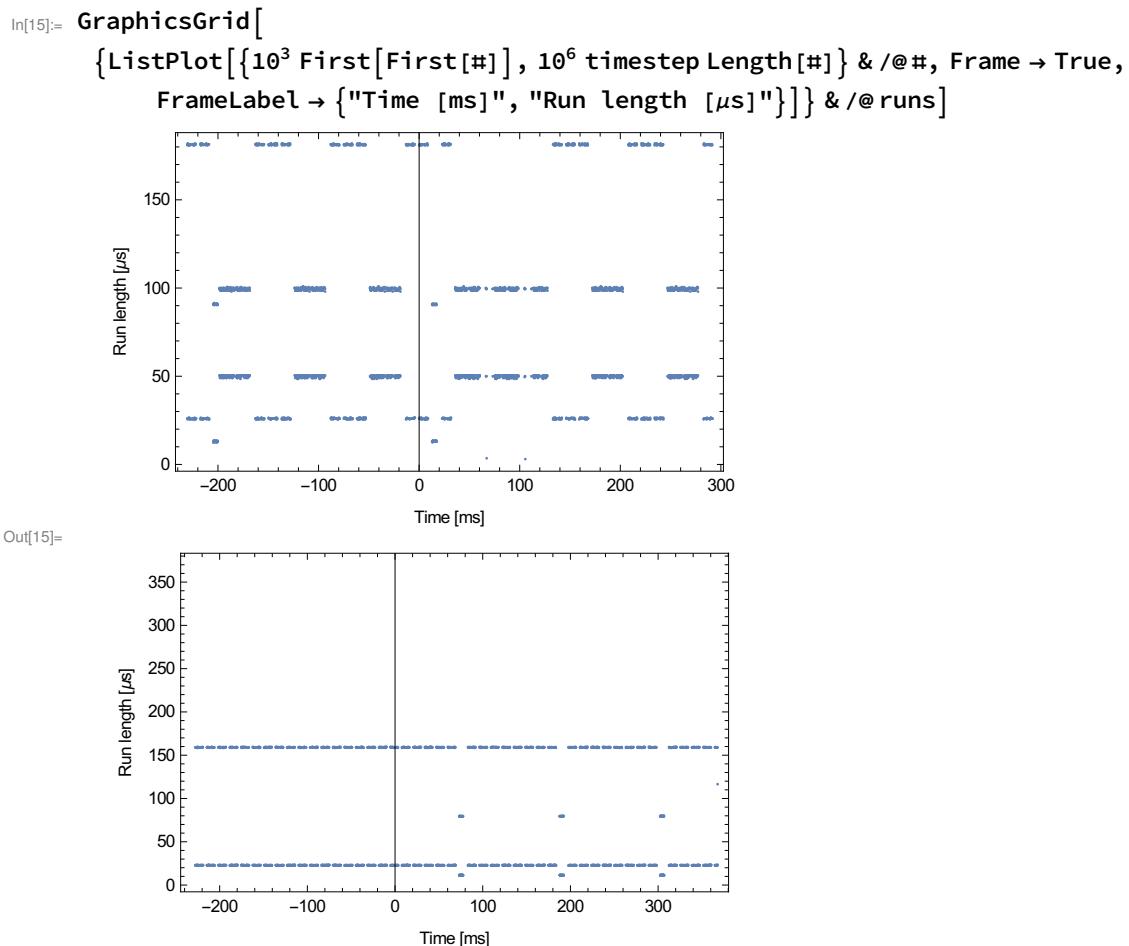


Runs of identical values for series

```
In[13]:= runs = SplitBy[#, Last] &/@digitized;
```

```
In[14]:= Length /@ runs
```

```
Out[14]= {4137, 3344}
```



There are outliers in the MM2 packet sequence ... maybe a switch packet?

Packets within the time series

Short data packets

MM format, see 2.2.9 Einbettung von Steuerbefehlen im MM-Format

Run length decoding

bit frame ($100\mu\text{s}$) per sampling step

```
In[17]:= timestep  
          10.^-4
```

Get run lengths of full traces

```
In[18]:= Length /@ (fullruns = SplitBy[#, Last] & /@ digitized)

Out[18]= {4137, 3344}
```

Run lengths in bit frames

```
In[19]:= rlbits = Map[ $\frac{\text{timestep}}{10^{-4}}$  Length[#] &, fullruns, {2}]

Out[19]= {{7.97, 0.26, 1.81, 0.26, 1.815, 1.815, 0.26, 0.255, 1.82, 1.815, 0.26, 0.26, 1.81,
  1.81, 0.26, 0.265, 1.815, 1.815, 0.26, 1.81, 0.26, 0.265, 1.81, 1.81, 0.26,
  0.26, 1.815, 0.255, 1.815, 0.26, 1.815, 1.81, 0.26, 1.815, 0.26, 0.255, 16.745,
  0.255, 1.815, 0.26, 1.815, 1.81, 0.26, 0.26, 1.815, 1.815, 0.26, 0.255, 1.815,
```


1.815, 0.26, 0.255, 1.815, 1.82, 0.255, 0.26, 1.82, 1.81, 0.26, 0.26, 1.81,
0.26, 1.81, 1.815, 0.26, 0.26, 16.75, 0.26, 1.815, 0.26, 1.815, 1.81, 0.26,
0.26, 1.82, 1.81, 0.26, 0.26, 1.81, 1.815, 0.26, 0.26, 1.815, 1.815, 0.26, 1.82,
0.26, 0.265, 1.82, 1.81, 0.26, 0.255, 1.815, 1.81, 0.265, 0.26, 1.815, 0.255,
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0.265, 0.255, 1.815, 1.81, 0.26, 0.26, 1.815, 0.255, 1.815, 0.265, 1.815, 1.81,
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1.81, 0.26, 0.26, 1.815, 1.815, 0.26, 0.26, 1.815, 0.255, 1.815, 0.26, 1.81,
1.82, 0.255, 1.815, 0.26, 0.255, 41.65, 1., 0.505, 1., 1., 0.505, 1., 0.5, 0.49,
0.99, 0.985, 0.985, 0.985, 0.99, 0.99, 0.99, 0.995, 0.505, 0.5, 0.505, 0.495,
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0.995, 0.5, 0.505, 0.5, 0.49, 0.985, 0.985, 0.995, 0.5, 0.495, 0.99, 0.99,
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0.505, 1., 0.995, 0.5, 0.98, 54.775, 0.255, 1.815, 0.26, 1.81, 1.81, 0.26,
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1., 0.505, 1., 1., 0.5, 1.005, 1., 0.5, 0.985, 14.955, 1., 0.5, 1., 0.995,
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Run length encoded data packets separated by run length >2 bits

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1.59, 0.23, 0.225, 1.595, 1.59, 0.23, 1.585, 0.23, 0.225, 1.59, 0.225, 1.59,
0.23, 1.59, 0.225, 1.59, 1.595, 0.225, 1.59, 0.225, 1.59, 0.235, 0.225}, {14.68},
{0.23, 1.59, 0.225, 1.59, 1.59, 0.225, 0.23, 1.59, 1.585, 0.23, 0.225, 1.59,
1.59, 0.225, 0.235, 1.59, 1.595, 0.23, 1.59, 0.235, 0.235, 0.23, 1.59, 0.23,
1.59, 0.225, 1.59, 0.225, 1.59, 0.23, 1.59, 0.235, 0.23}, {37.405}, {0.23, 1.59,
0.23, 1.59, 1.59, 0.225, 0.225, 1.595, 0.225, 0.225, 1.59, 1.59, 0.23,
0.225, 1.59, 1.59, 0.23, 0.23, 1.59, 1.59, 0.23, 0.225, 0.225, 1.59, 1.59, 0.23,
1.59, 1.59, 0.23, 0.225, 1.59, 1.59, 0.225, 1.59, 0.225, 1.59, 0.235, 1.165}}}}
```

In[21]:= Dimensions /@ rlruns

Out[21]= {{129}, {186}}

```
In[22]:= Map[Length, rlrungs, {2}]
Out[22]= {{1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 197, 1, 83, 1, 83, 1, 35, 1,
35, 1, 35, 1, 35, 1, 35, 1, 197, 1, 83, 1, 83, 1, 35, 1, 35, 1, 35,
1, 35, 1, 35, 1, 197, 1, 83, 1, 83, 1, 35, 1, 35, 1, 35, 1, 35,
1, 35, 1, 35, 1, 35, 1, 346, 1, 10, 1, 5, 1, 83, 1, 232, 1, 10, 1, 5, 1, 83,
1, 83, 1, 35, 1, 35, 1, 35, 1, 35, 1, 197, 1, 83, 1, 83, 1, 35,
1, 35, 1, 35, 1, 35, 1, 35, 1, 197, 1, 83, 1, 83, 1, 35, 1, 35, 1},
{1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35,
35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1,
35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1,
35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1,
1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1,
35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35,
1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35,
1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35, 1, 35}}
```

Length of packet separators in 100 μ s bit frames

```
In[23]:= TableForm[Select[#, Length[#] <= 1 &]] &/@ rlrungs
```

37.025	
14.685	
37.4	
14.685	
37.395	
14.685	
37.405	
14.68	
37.4	
14.68	
37.4	
14.685	
37.385	
14.68	
7.97	37.395
16.745	14.68
42.645	37.395
16.74	14.685
41.645	37.405
8.37	14.68
15.85	37.395
14.955	14.69
14.955	37.39
54.775	14.68
16.745	37.4
42.64	14.68
16.75	37.395
42.645	14.68
16.745	37.4
41.65	14.69
14.95	37.4
14.95	14.68
54.775	37.4
16.745	14.69
42.635	37.405
16.745	14.685
42.64	37.395
16.745	14.685
41.645	37.405

```
Out[23]= {14.96, 14.68, 14.95, 37.4, 54.775, 14.68, 16.74, 37.395, 42.645, 14.69, 16.745, 37.4, 41.645, 14.685, 8.37, 36.515, 55.675, 7.34, 16.745, 48.825, 41.645, 14.685, 60.22, 37.4, 60.19, 14.68, 15.935, 37.395, 14.95, 14.685, 60.225, 37.405, 60.2, 14.685, 15.94, 37.405, 14.955, 14.685, 54.785, 37.4, 16.74, 14.685, 42.65, 37.405, 16.745, 14.69, 42.65, 37.39, 16.745, 14.685, 41.645, 36.52, 14.955, 7.335, 14.95, 48.83, 54.78, 14.685, 16.745, 37.4, 42.645, 14.685, 16.75, 37.405, 42.65, 14.685, 16.74, 37.395, 41.655, 14.685, 14.955, 37.405, 14.955, 14.685, 54.795, 37.39, 16.74, 14.685, 13.24, 37.39, 14.685, 37.395, 14.685, 36.515, 7.34, 48.82, 14.685, 37.39, 14.685, 37.39, 14.69, 37.405, 14.68, 37.405}
```

Run length encoded packets

Display number of runs per packet

Parse runs

Shotgun MM parser

for locomotives

```
In[29]:= MMparser = Function[{in, out},
  If[Length[in] ≥ 2,
    Which[Take[in, 2] == {2, 13} ∨ Take[in, 2] == {2, 14} ∨ Take[in, 2] == {2, 15},
      {Drop[in, 2], Append[out, 0]},
      Take[in, 2] == {13, 2} ∨ Take[in, 2] == {14, 2} ∨ Take[in, 2] == {15, 2},
      {Drop[in, 2], Append[out, 1]},
      True, {Drop[in, 1], Append[out, △]}],
    If[Length[in] == 1,
      Which[{2} == Take[in, 1], {Drop[in, 1], Append[out, 0]}, Take[in, 1] == {13} ∨
        Take[in, 1] == {14} ∨ Take[in, 1] == {15}, {Drop[in, 1], Append[out, 1]},
        True, {Drop[in, 1], Append[out, △]}], {Drop[in, 1], Append[out, △]}]
    ]
  ]
Out[29]= Function[{in, out}, If[Length[in] ≥ 2,
  Which[Take[in, 2] == {2, 13} || Take[in, 2] == {2, 14} || Take[in, 2] == {2, 15},
    {Drop[in, 2], Append[out, 0]},
    Take[in, 2] == {13, 2} || Take[in, 2] == {14, 2} || Take[in, 2] == {15, 2},
    {Drop[in, 2], Append[out, 1]}, True, {Drop[in, 1], Append[out, △]}],
  If[Length[in] == 1, Which[{2} == Take[in, 1], {Drop[in, 1], Append[out, 0]},
    Take[in, 1] == {13} || Take[in, 1] == {14} || Take[in, 1] == {15},
    {Drop[in, 1], Append[out, 1]}, True, {Drop[in, 1], Append[out, △]}],
    {Drop[in, 1], Append[out, △]}]]]
```

for magnets

```
In[30]:= MMmagparser = Function[{in, out},
  If[Length[in] ≥ 2, Which[{1, 6} == Take[in, 2] ∨ {1, 7} == Take[in, 2],
    {Drop[in, 2], Append[out, 0]}, {6, 1} == Take[in, 2] ∨ {7, 1} == Take[in, 2],
    {Drop[in, 2], Append[out, 1]}, True, {Drop[in, 1], Append[out, △]}],
  If[Length[in] == 1, Which[{1} == Take[in, 1], {Drop[in, 1], Append[out, 0]},
    {6} == Take[in, 1] ∨ {7} == Take[in, 1], {Drop[in, 1], Append[out, 1]},
    True, {Drop[in, 1], Append[out, △]}], {Drop[in, 1], Append[out, △]}]]
Out[30]= Function[{in, out},
  If[Length[in] ≥ 2, Which[{1, 6} == Take[in, 2] || {1, 7} == Take[in, 2],
    {Drop[in, 2], Append[out, 0]}, {6, 1} == Take[in, 2] || {7, 1} == Take[in, 2],
    {Drop[in, 2], Append[out, 1]}, True, {Drop[in, 1], Append[out, △]}],
  If[Length[in] == 1, Which[{1} == Take[in, 1], {Drop[in, 1], Append[out, 0]},
    {6} == Take[in, 1] || {7} == Take[in, 1], {Drop[in, 1], Append[out, 1]},
    True, {Drop[in, 1], Append[out, △]}], {Drop[in, 1], Append[out, △]}]]]
```


Motorola format trit

```
In[38]:= mmtrit = Function[{in, out},
  If[Length[in] < 2, {Drop[in], Append[out, ERROR]}, {Drop[in, 2],
    Append[out, Switch[Take[in, 2], {0, 0}, 0, {1, 1}, 1, {1, 0}, 2, _, \[Delta]]]}]
  ]
]

Out[38]= Function[{in, out}, If[Length[in] < 2,
  {Drop[in], Append[out, ERROR]}, {Drop[in, 2], Append[out, Switch[Take[in, 2],
  {0, 0}, 0,
  {1, 1}, 1,
  {1, 0}, 2,
  _, \[Delta]]]}]]
```

Motorola format 4-trit address (address 80, all open, is unassigned)

```
In[39]:= mmaddress = Function[{in, out}, If[Length[in] < 8, {Drop[in], Append[out, ERROR]}, {
  {\#1[[1]], Append[out, {ADDR, FromDigits[Reverse[Last[\#1]], 3]}]} &) [
  Nest[mmtrit @@ \#1 &, {in, out}, 4]]]]

Out[39]= Function[{in, out}, If[Length[in] < 8, {Drop[in], Append[out, ERROR]}, {
  {\#1[[1]], Append[out, {ADDR, FromDigits[Reverse[Last[\#1]], 3]}]} &) [
  Nest[mmtrit @@ \#1 &, {in, out}, 4]]]]

In[40]:= Map[mmaddress[\#, {}] &, Most[mmbitseq], {1}]

Out[40]= {{{1, 1, 0, 0, 0, 0, 0, 1, 1, 0}, {{ADDR, 78}}}, {{1, 1, 0, 0, 0, 0, 1, 1, 1, 0}, {{ADDR, 78}}}, {{1, 1, 0, 0, 0, 1, 0, 1, 1, 0}, {{ADDR, 78}}}, {{1, 1, 0, 0, 0, 1, 1, 1, 1, 0}, {{ADDR, 78}}}, {{1, 1, 0, 1, 0, 0, 0, 1, 1, 0}, {{ADDR, 78}}}, {{1, 1, 0, 1, 0, 0, 1, 1, 1, 0}, {{ADDR, 78}}}, {{1, 1, 0, 1, 0, 1, 0, 0, 1, 1, 0}, {{ADDR, 78}}}, {{1, 1, 0, 1, 0, 1, 0, 1, 1, 1, 0}, {{ADDR, 78}}}, {{1, 1, 0, 1, 0, 1, 1, 0, 0, 1, 0}, {{ADDR, 78}}}, {{1, 1, 0, 1, 0, 1, 1, 1, 1, 1, 0}, {{ADDR, 78}}}, {{1, 1, 1, 1, 0, 0, 1, 1, 1, 1, 0}, {{ADDR, 78}}}, {{1, 1, 1, 1, 1, 1, 0, 0, 1, 1, 0}, {{ADDR, 78}}}}
```

Motorola format parser

4-trit address, one function (double) bit, 4 velocity (double) bits

```
In[41]:= mm1parse =
Function[{in, out},
({#1, Append[Drop[#2, -4], {SPEED, FromDigits[Reverse[Take[#2, -4]], 2]}]} &) @@
Nest[mmbit @@ #1 &, ({#1[[1]], Append[Most[#1[[2]]], {FUNC, Last[#1[[2]]]}]} &) [
mmbit @@ mmaddress[in, out]], 4]]

Out[41]= Function[{in, out},
({#1, Append[Drop[#2, -4], {SPEED, FromDigits[Reverse[Take[#2, -4]], 2]}]} &) @@
Nest[mmbit @@ #1 &, ({#1[[1]], Append[Most[#1[[2]]], {FUNC, Last[#1[[2]]]}]} &) [
mmbit @@ mmaddress[in, out]], 4]]

In[42]:= mm2dataparse = Function[{in, out}, If[8 != Length[in], {in, Append[out, ERROR]}, 
Block[{speed = FromDigits[in[[7, 5, 3, 1]], 2],
data = in[[2, 4, 6, 8]], tag}, tag = Which[
data == {1, 0, 1, 0} & speed > 7, {REVERSE},
data == {1, 0, 1, 1} & speed < 8, {REVERSE},
data == {0, 1, 0, 1} & speed < 8, {FORWARD},
data == {0, 1, 0, 0} & speed > 7, {FORWARD},
True, {DATA, data}];
{Drop[in, 8], Join[out, {{SPEED, speed}, tag}}}]
]
]
]

Out[42]= Function[{in, out}, If[8 != Length[in], {in, Append[out, ERROR]}, 
Block[{speed = FromDigits[in[[7, 5, 3, 1]], 2], data = in[[2, 4, 6, 8]], tag},
tag = Which[data == {1, 0, 1, 0} && speed > 7, {REVERSE},
data == {1, 0, 1, 1} && speed < 8, {REVERSE}, data == {0, 1, 0, 1} && speed < 8,
{FORWARD}, data == {0, 1, 0, 0} && speed > 7, {FORWARD}, True, {DATA, data}];
{Drop[in, 8], Join[out, {{SPEED, speed}, tag}}}]]

In[43]:= mm2parse =
Function[{in, out},
mm2dataparse @@ (({#1[[1]], Append[Most[#1[[2]]], {FUNC, Last[#1[[2]]]}]} &) [
mmbit @@ mmaddress[in, out]]))

Out[43]= Function[{in, out}, mm2dataparse @@
({#1[[1]], Append[Most[#1[[2]]], {FUNC, Last[#1[[2]]]}]} &) [mmbit @@ mmaddress[in, out]]]
```

Parse Motorola packets

```
In[44]:= Last[mm1parse[#, {}]] & /@ Most[mmbitseq]
Out[44]= {{ { ADDR, 78}, { FUNC, 1}, { SPEED, 12  $\Delta$ } },
{ { ADDR, 78}, { FUNC, 1}, { SPEED, 4 (1 + 2  $\Delta$ ) } }, { { ADDR, 78}, { FUNC, 1}, { SPEED, 14  $\Delta$ } },
{ { ADDR, 78}, { FUNC, 1}, { SPEED, 2 ( $\Delta$  + 2 (1 + 2  $\Delta$ ) ) } },
{ { ADDR, 78}, { FUNC, 1}, { SPEED, 13  $\Delta$ } },
{ { ADDR, 78}, { FUNC, 1}, { SPEED,  $\Delta$  + 4 (1 + 2  $\Delta$ ) } }, { { ADDR, 78}, { FUNC, 1}, { SPEED, 11  $\Delta$ } },
{ { ADDR, 78}, { FUNC, 1}, { SPEED, 15  $\Delta$ } }, { { ADDR, 78}, { FUNC, 1}, { SPEED, 15  $\Delta$ } },
{ { ADDR, 78}, { FUNC, 1}, { SPEED,  $\Delta$  + 2 ( $\Delta$  + 2 (1 + 2  $\Delta$ ) ) } },
{ { ADDR, 78}, { FUNC, 1}, { SPEED, 1 + 4 (1 + 2  $\Delta$ ) } },
{ { ADDR, 78}, { FUNC, 1}, { SPEED, 1 + 14  $\Delta$ } } }

In[45]:= mm2parse[#, {}] & /@ Most[mmbitseq]
Out[45]= {{ {}, { { ADDR, 78}, { FUNC, 1}, { SPEED, 8}, { DATA, { 0, 0, 1, 0 } } } },
{ {}, { { ADDR, 78}, { FUNC, 1}, { SPEED, 12}, { DATA, { 0, 0, 1, 0 } } } },
{ {}, { { ADDR, 78}, { FUNC, 1}, { SPEED, 8}, { DATA, { 0, 1, 1, 0 } } } },
{ {}, { { ADDR, 78}, { FUNC, 1}, { SPEED, 12}, { DATA, { 0, 1, 1, 0 } } } },
{ {}, { { ADDR, 78}, { FUNC, 1}, { SPEED, 8}, { REVERSE } } },
{ {}, { { ADDR, 78}, { FUNC, 1}, { SPEED, 12}, { REVERSE } } },
{ {}, { { ADDR, 78}, { FUNC, 1}, { SPEED, 8}, { DATA, { 1, 1, 0, 0 } } } },
{ {}, { { ADDR, 78}, { FUNC, 1}, { SPEED, 8}, { DATA, { 1, 1, 1, 0 } } } },
{ {}, { { ADDR, 78}, { FUNC, 1}, { SPEED, 12}, { DATA, { 1, 1, 0, 0 } } } },
{ {}, { { ADDR, 78}, { FUNC, 1}, { SPEED, 12}, { DATA, { 1, 1, 1, 0 } } } },
{ {}, { { ADDR, 78}, { FUNC, 1}, { SPEED, 13}, { REVERSE } } },
{ {}, { { ADDR, 78}, { FUNC, 1}, { SPEED, 11}, { REVERSE } } }

In[46]:= Last[mm1parse[#, {}]] & /@ Most[mmmagbitseq]
Out[46]= {{ { ADDR, 78}, { FUNC, 1}, { SPEED, 0 } }}}
```