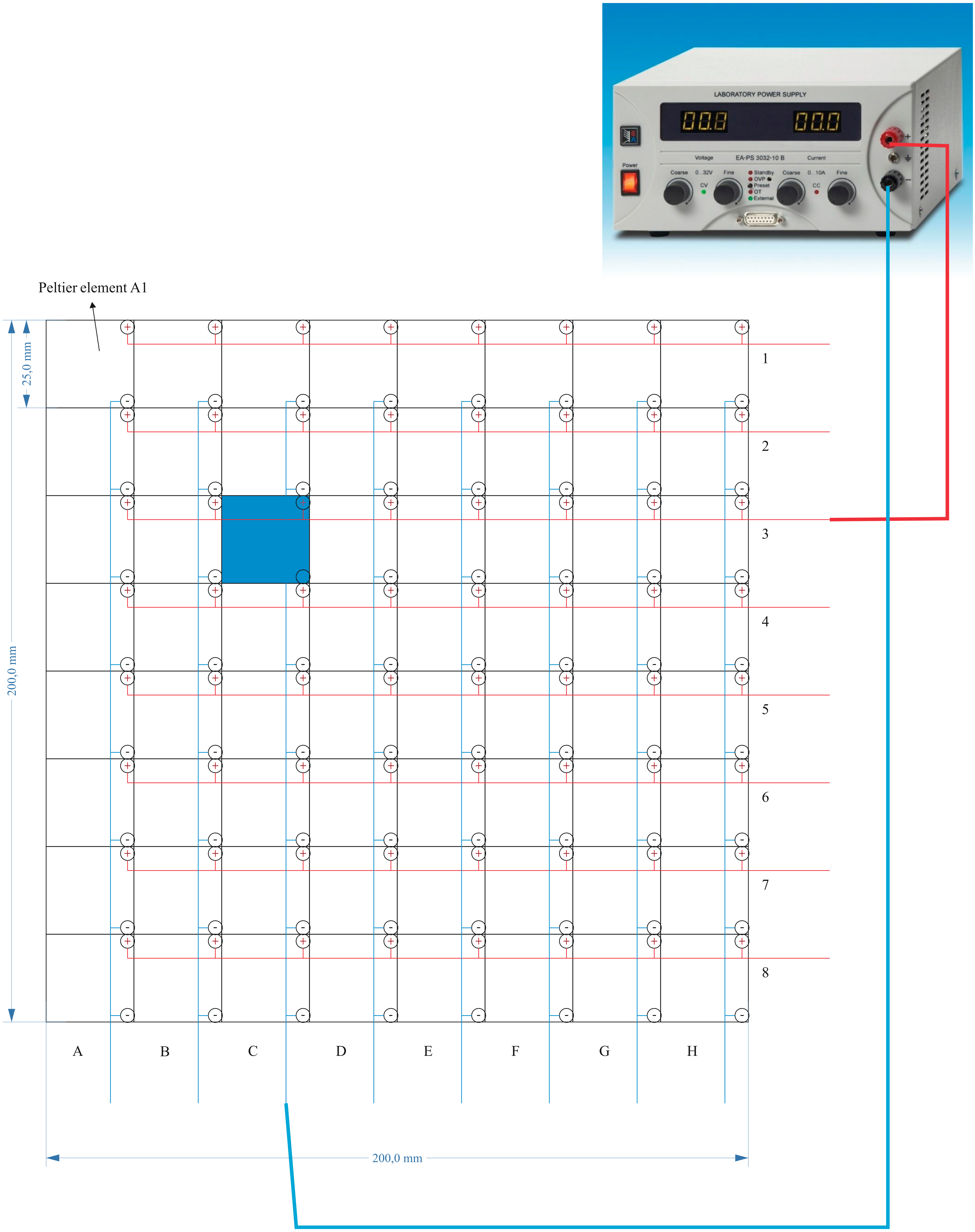
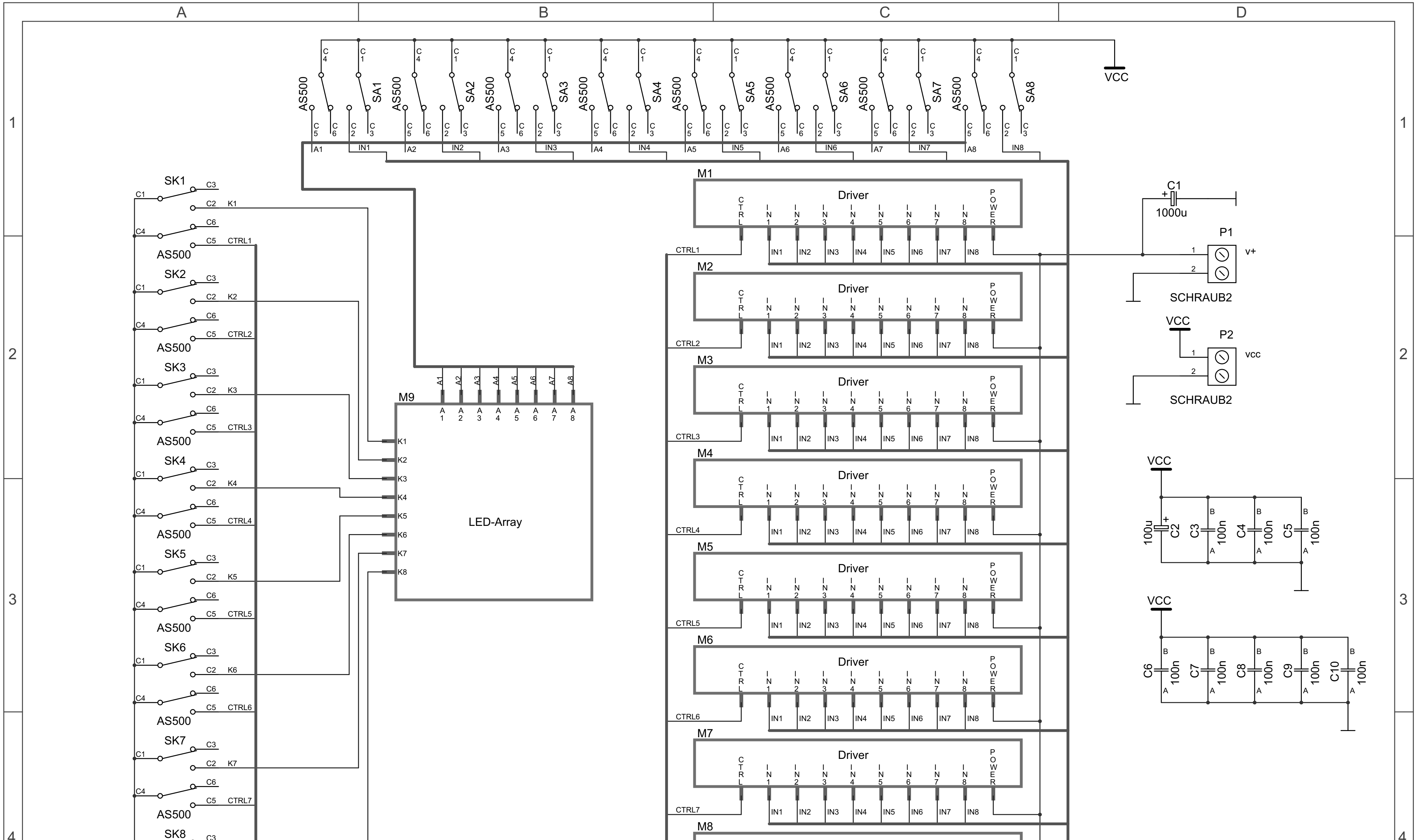
# Supplementary Information

## A novel thermal-visual place learning paradigm for honeybees (*Apis mellifera*)

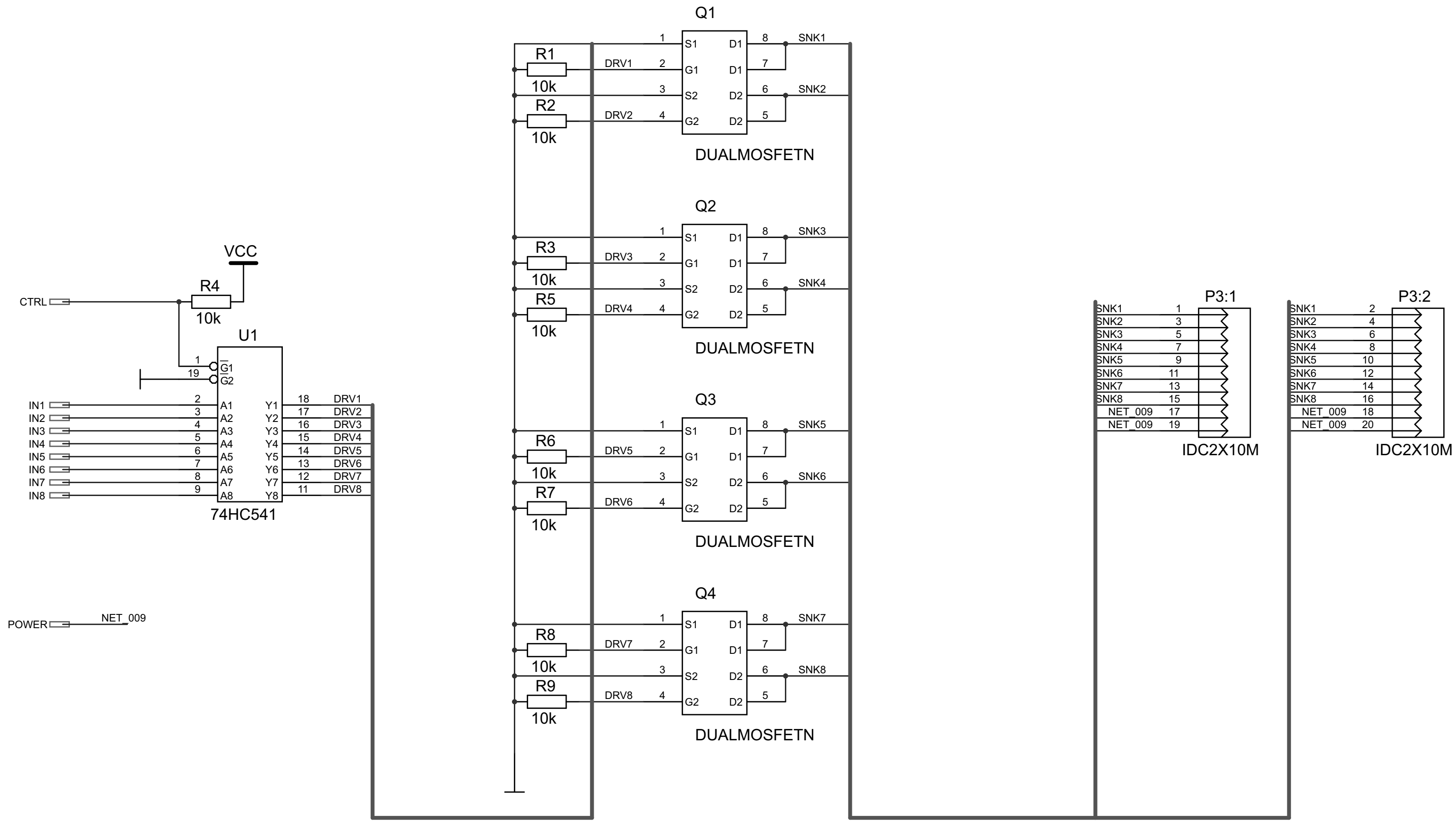
Scheiner et al.



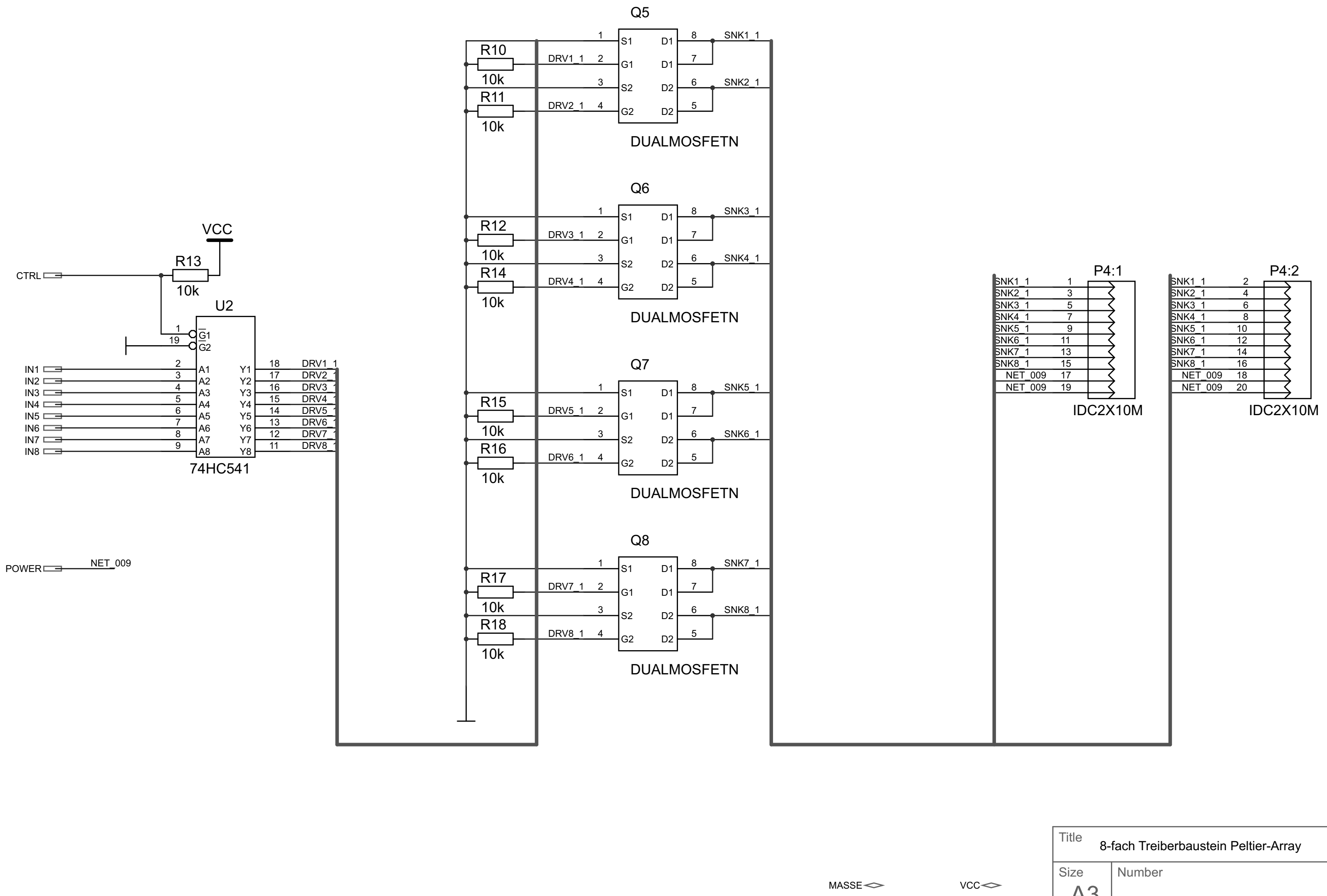
LABORATORY POWER SUPPLY
Voltage
EA-PS 3032-10 B
Current
Power
Coarse
0...32V
Fine
CV
Standby
OVP
Preset
OT
External
Coarse
0...10A
Fine
CC
Peltier element A1
25,0 mm
200,0 mm
1
2
3
4
5
6
7
8
A
B
C
D
E
F
G
H
200,0 mm



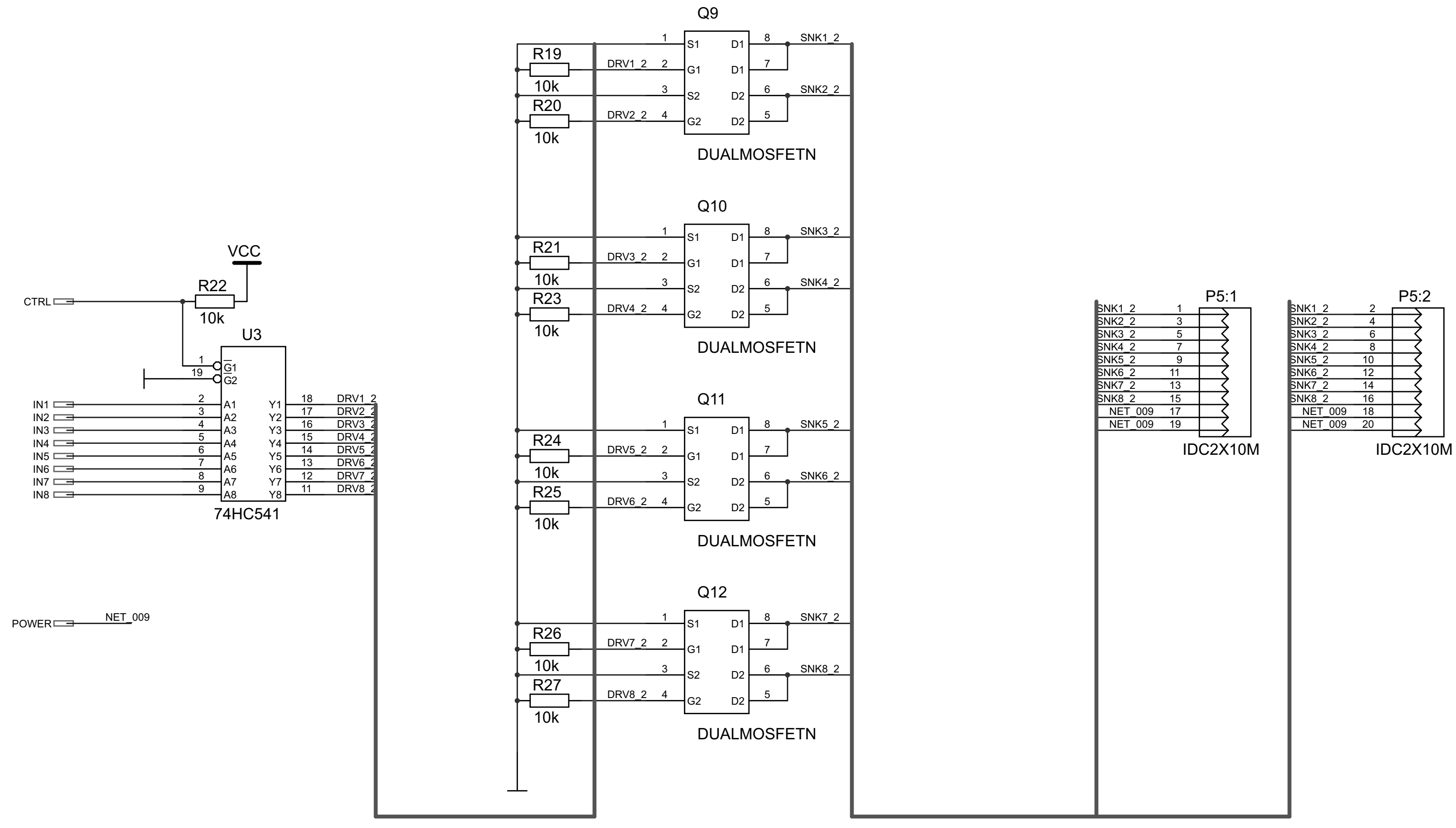

| Title | Switchboard Peltier-Array | |
|---|---|---|
| Size: A3 | Number | Rev |
| Date: 24.11.2015 | | Drawn by |
| Filename: PELTSW.S01 | | Sheet of |




| | | | |
|---|---|---|---|
| Title | 8-fach Treiberbaustein Peltier-Array | | |
| Size A3 | Number | | Rev |
| Date | 24.11.2015 | Drawn by | |
| Filename | PELTSW3.S01 | Sheet | of |

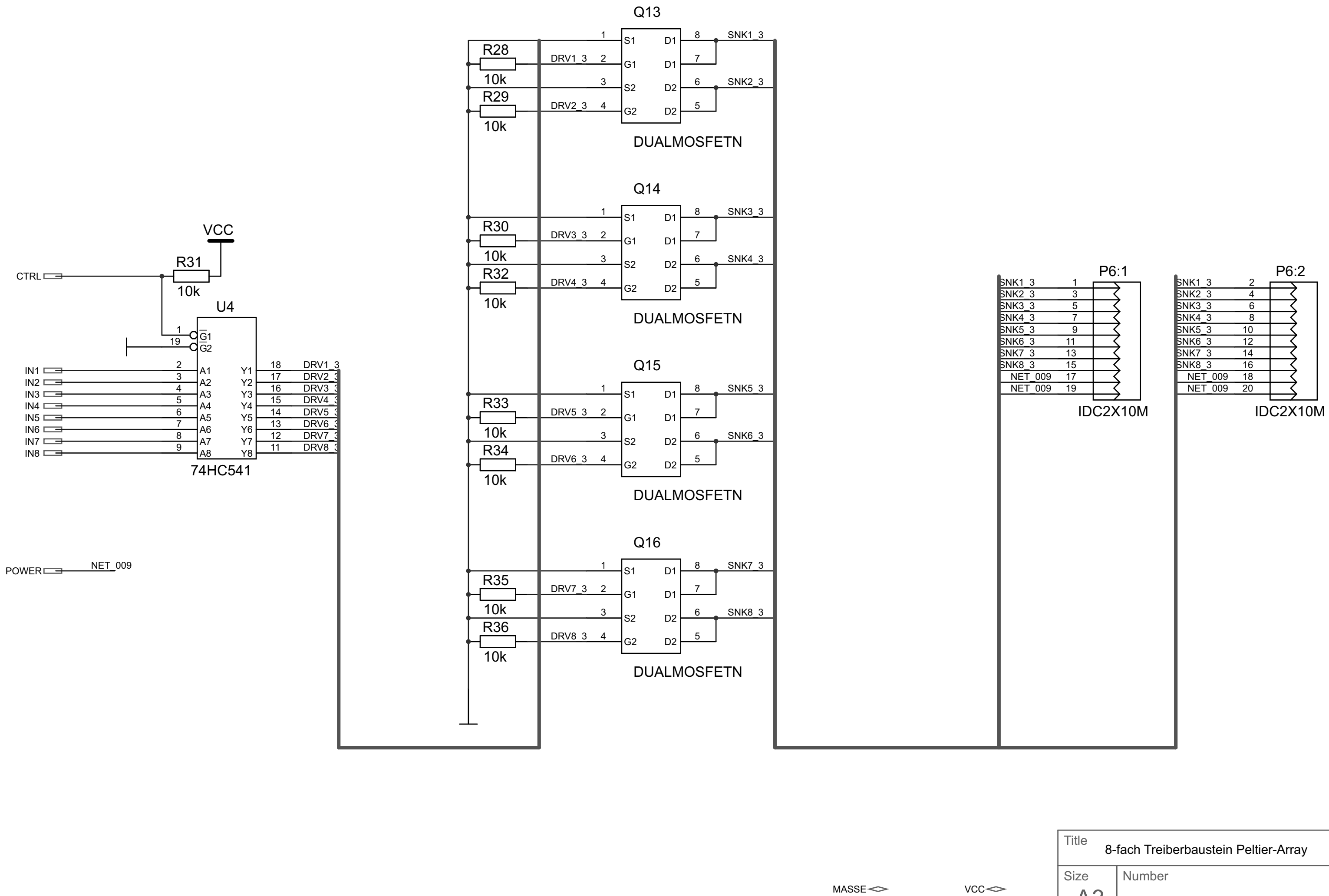



| | | | |
|---|---|---|---|
| Title | 8-fach Treiberbaustein Peltier-Array | | |
| Size A3 | Number | | Rev |
| Date 24.11.2015 | | Drawn by | |
| Filename PELTSW3.S01 | | Sheet | of |

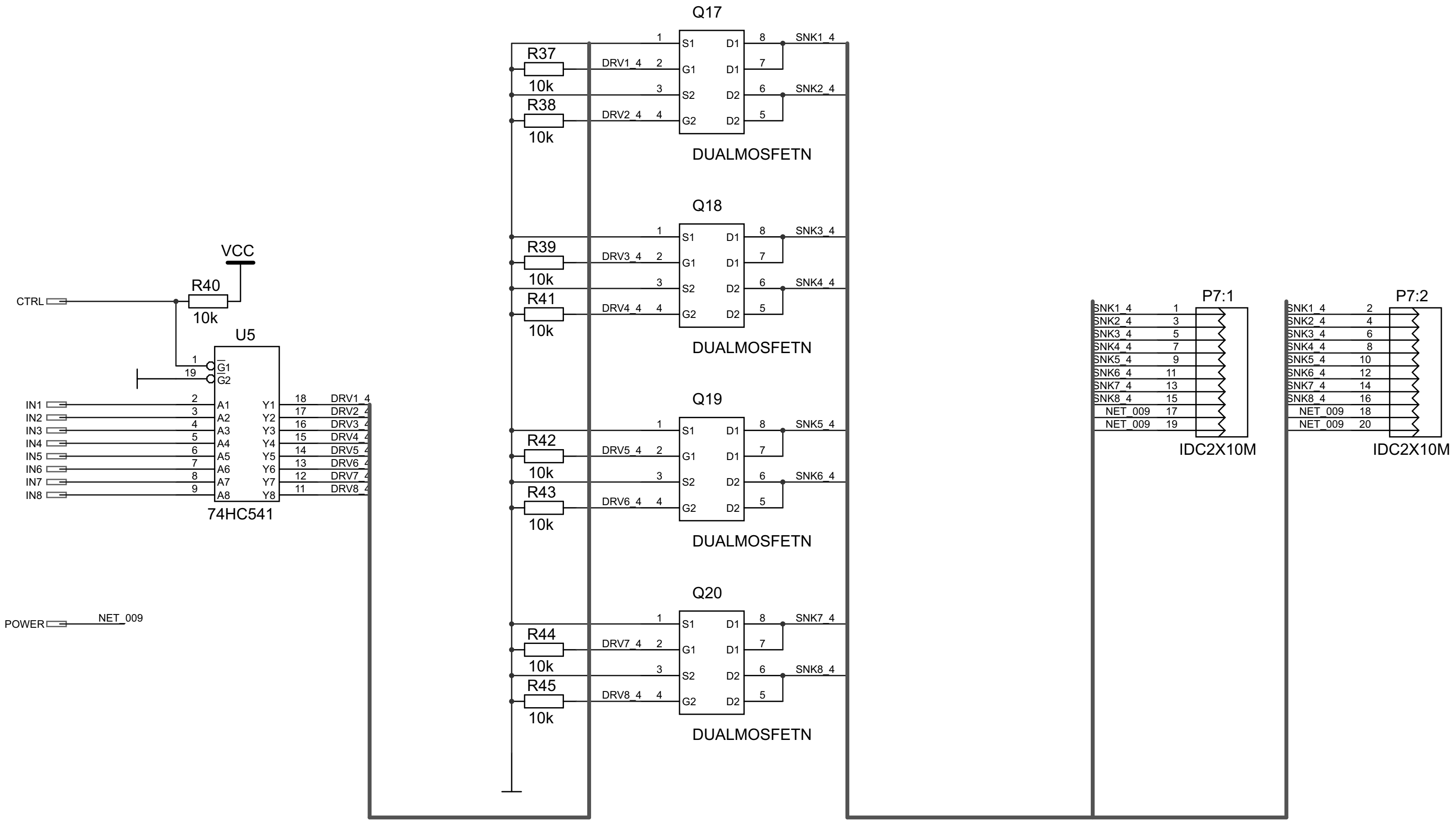



MASSE VCC

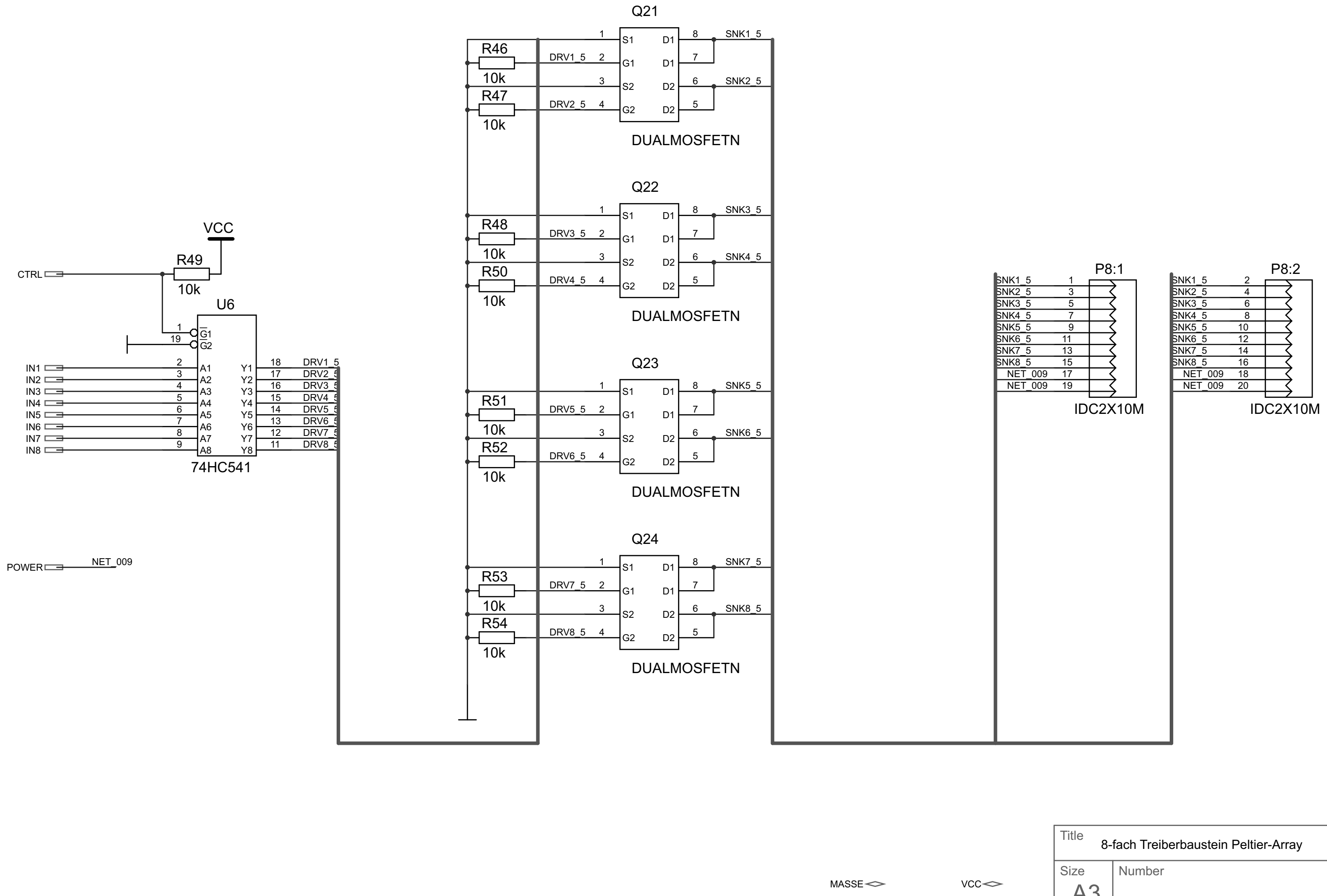
| | | | |
|---|---|---|---|
| Title | 8-fach Treiberbaustein Peltier-Array | | |
| Size A3 | Number | | Rev |
| Date 24.11.2015 | | Drawn by | |
| Filename PELTSW3.S01 | | Sheet | of |



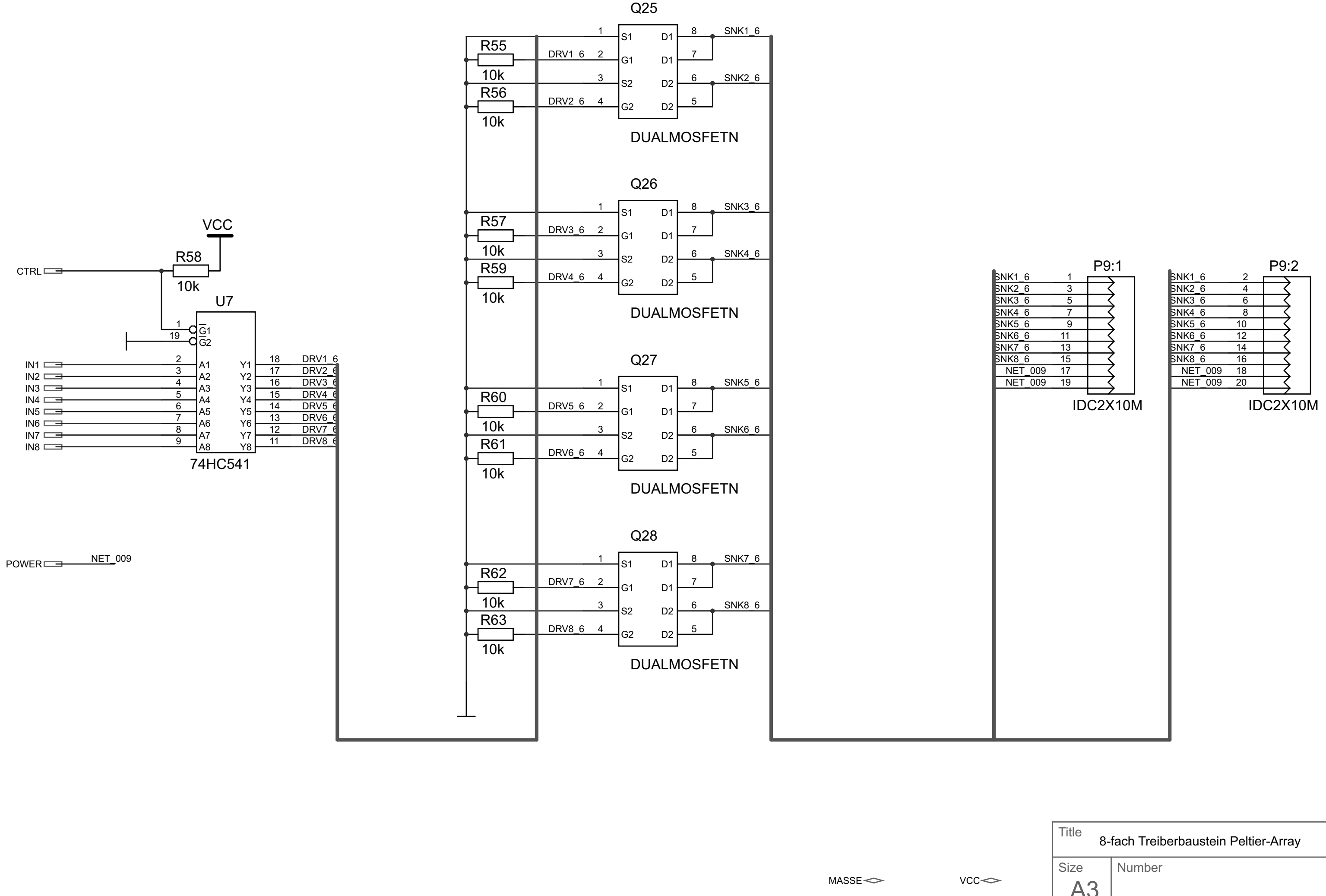

| | | | |
|---|---|---|---|
| Title | 8-fach Treiberbaustein Peltier-Array | | |
| Size A3 | Number | | Rev |
| Date | 24.11.2015 | Drawn by | |
| Filename | PELTSW3.S01 | Sheet | of |



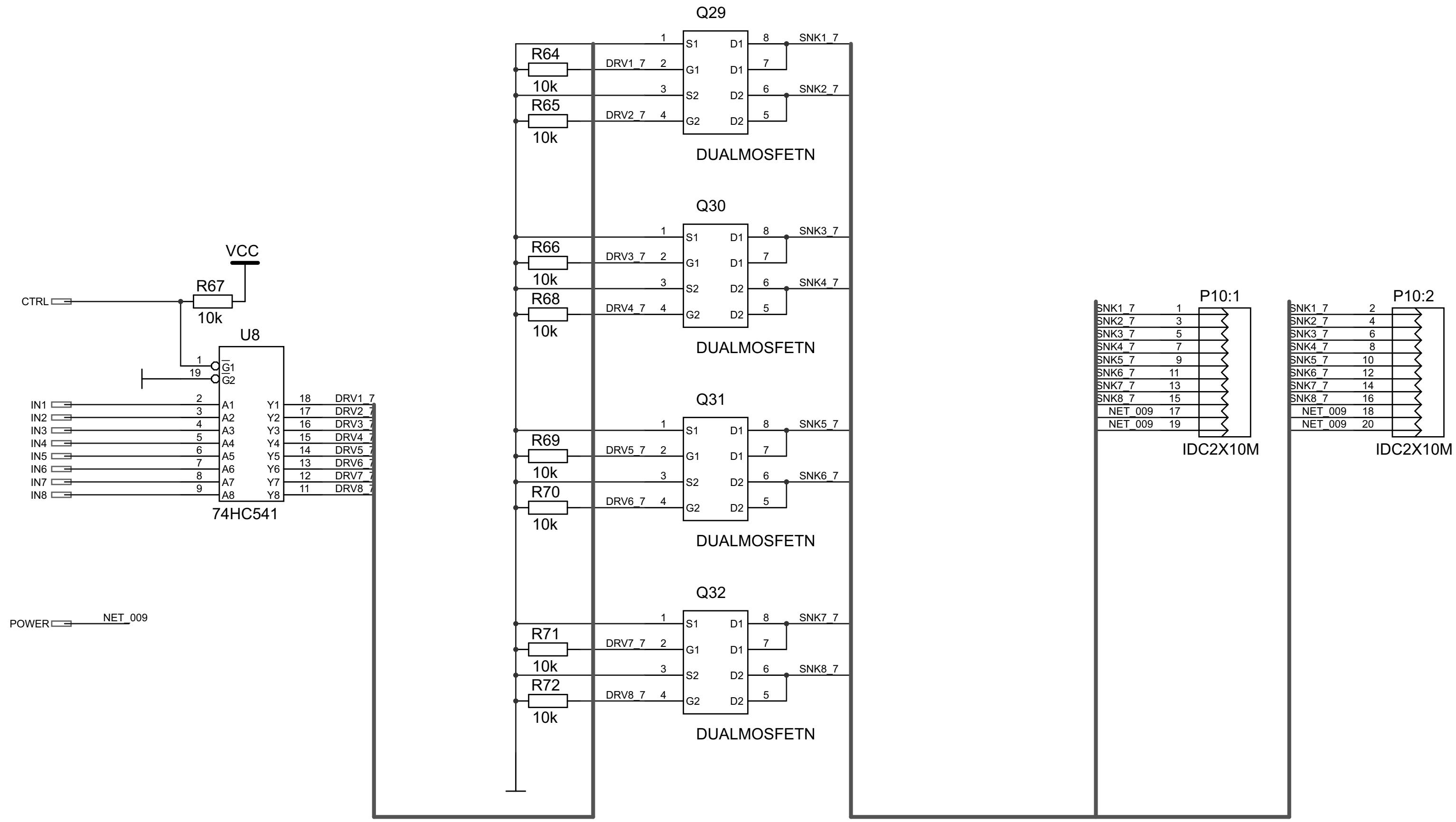

| | | |
|---|---|---|
| Title | 8-fach Treiberbaustein Peltier-Array | |
| Size A3 | Number | Rev |
| Date 24.11.2015 | | Drawn by |
| Filename PELTSW3.S01 | | Sheet of |




| | | | |
|---|---|---|---|
| Title | 8-fach Treiberbaustein Peltier-Array | | |
| Size A3 | Number | | Rev |
| Date 24.11.2015 | | Drawn by | |
| Filename PELTSW3.S01 | | Sheet of | |



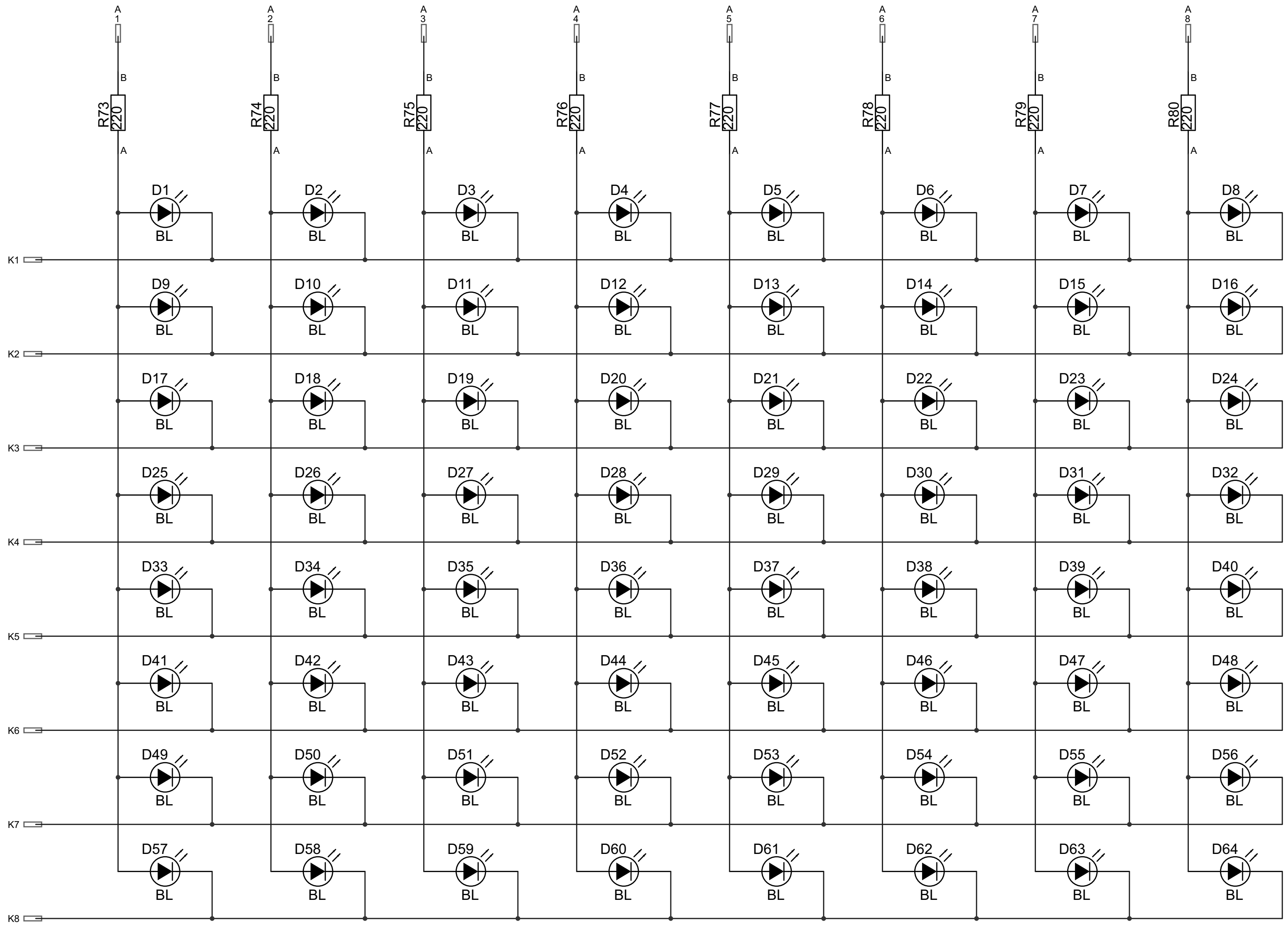

| | | |
|---|---|---|
| Title: 8-fach Treiberbaustein Peltier-Array | | |
| Size: A3 | Number | Rev |
| Date: 24.11.2015 | | Drawn by |
| Filename: PELTSW3.S01 | | Sheet of |




MASSE

VCC

| Title | 8-fach Treiberbaustein Peltier-Array | | |
|---|---|---|---|
| Size A3 | Number | | Rev |
| Date | 24.11.2015 | Drawn by | |
| Filename | PELTSW3.S01 | Sheet | of |




| | | |
|---|---|---|
| Title | LED-Array Display Peltier-Array | |
| Size A3 | Number | Rev |
| Date 24.11.2015 | | Drawn by |
| Filename PELTSW2.S01 | | Sheet of |

```
# Calculate track characteristics from Ctrax data
# for Ctrax see: Ctrax: The Caltech Multiple Walking Fly Tracker
# http://ctrax.sourceforge.net/
# Main characteristic: sector assignment
# for different insects
# for different time windows (complete, 30, 60, 120, 30-90 sec.)
# Last updated: 10.3.2020, 28.06.2017
# By: Felix Frantzmann, Oliver Mitesser

# initialize data frame for output
d<-data.frame()

####################################################################
# Read time series of positions from file
# file format: Ctrax
####################################################################

# read data file
z=read.table(file=file.choose() , header=F, sep=";", dec=".")

####################################################################

# set file for R terminal output
sink("RTerminalOutput.txt")

# define center and radius of arena in pixel coordinates
# resolution 1296x972
r0=481
cx=644
cy=481

# position cold spot
# rectanle upper right
RORx=514
# transform to R:
RORy=972-602
# rectangle upper left
ROLx=398
# transform to R:
ROLy=972-602
# rectangle lower left
RULx=398
# transform to R:
RULy=972-714
# rectangle lower right
RURx=514
# transform to R:
RURy=972-714

# calculate data characteristics
# number of columns in data frame
n=length(z[1,])
# number of lines in data frame
m=length(z[,1])
```

```
# initialize vector of fly ids
flyindex=c(0)

# define pdf file for graphical output
pdf("RGraphicalOutput.pdf")

# repeat for each fly
for (i in flyindex){

  # initialize sector assignment vector for positions
  sec=rep(4,length(z[,1]))

  # set starting column for current fly
  id=i*6+1

  # calculate position angles of current track positions in polar
coordinates
  ang=atan2(z[,id+2]-cy,z[,id+1]-cx)
  ang[ang<0]=ang[ang<0]+2*pi

  # determine vector of sector for all position angles
  sec[ang > 0 & ang < (pi/2)]=2
  sec[ang > (pi/2) & ang < pi]=1
  sec[ang > pi & ang < (3/2*pi)]=4
  sec[ang > (3/2*pi) & ang < 2*pi]=3

  # determine if fly position is outside of cold spot
  raus=((z[,id+1]<rep(RULx,m)) | (z[,id+1]>rep(RURx,m)) |
(z[,id+1]>rep(RULx,m)) & (z[,id+1]<rep(RURx,m)) &
(z[,id+2]<rep(RURy,m)) | (z[,id+1]>rep(RULx,m)) &
(z[,id+1]<rep(RURx,m)) & (z[,id+2]>rep(RORy,m)))

  # determine when spot was left for the first time
  zuerstrausCS=min(which(raus==1))


###################################################################
  # Output diagnostics

###################################################################
  print(i)
  print("No. of frame after leaving the CS")
  print(zuerstrausCS)

  # vector of starting time steps for different time intervals
  sttoffvec=c(0,0,0,0,1080,1080)
  # vector of ending time steps for different time intervals
  endoffvec=c(1080,2160,3240,4320,2160,3240)

  # matrix to collect sector statistics
  ymat=matrix(ncol=12, nrow=length(sttoffvec)+1)

  # calculate first entering for each of the 4 sectors
```

```
  print("first in 1"); zuerstin1=min(which(sec==1));
print(zuerstin1)
  print("first in 2"); zuerstin2=min(which(sec==2));
print(zuerstin2)
  print("first in 3"); zuerstin3=min(which(sec==3));
print(zuerstin3)
  print("first in 4"); zuerstin4=min(which(sec==4));
print(zuerstin4)
  print("************")
  # end of diagnostic output

##################################################################

  # arrival in target 1
  targetsec=zuerstin1

  # duration until arrival in target sector
  q=(targetsec-zuerstrausCS)

  # define vector for distributions
  alldis=c()

  # calculate print distribution for different time slots
  for (jdis in 0:length(sttoffvec)){

    # define relevant time interval
    if (jdis==0) intrvl=1:length(sec) else
intrvl=(zuerstrausCS+sttoffvec[jdis]):(zuerstrausCS+endoffvec[jdis])

    # calculate sector distribution

disxxx=c(sum(sec[intrvl]==1),sum(sec[intrvl]==2),sum(sec[intrvl]==3)
,sum(sec[intrvl]==4))
    alldis=c(alldis,as.vector(disxxx))

    # provide terminal output
    if (jdis==0) {print ("distribution")} else {
      print(paste("distribution from ",sttoffvec[jdis]/60, "sec.
after leaving CS till", endoffvec[jdis]/60, "sec."))}
    print(disxxx)

    # calculate sector transitions
    # initialize vector to collect transition data
    nvec=rep(0,12)
    secmat=expand.grid(1:4,1:4)[c(-1,-6,-11,-16),]
    for (j in 1:(length(sec[intrvl])-1)){
      for (isec in 1:12) if (sec[j]==secmat[isec,1] &
sec[j+1]==secmat[isec,2]) nvec[isec]=nvec[isec]+1
    }

    # terminal output of sector transitions
    if (jdis==0) {print ("distribution")} else {
      print(paste("transitions from ",sttoffvec[jdis]/60, "sec.
after leaving CS till", endoffvec[jdis]/60, "sec."))}
```

```
    # sort output for consisteny with table headings
    ymat[jdis+1,]=nvec[c(4,1,8,5,7,2,10,3,11,6,12,9)]

    # terminal output
    print(ymat[jdis+1,])
    #----


###################################################################
    # Graphical output

###################################################################
    # plot arena
    plot(z[intrvl,id+1], z[intrvl,id+2], pch=10, col=sec[intrvl],
cex=0.5, xlab="x", ylab="y", xlim=c(0,1288), ylim=c(0,996),
main="path 60s", ann=FALSE, axes=FALSE)
    lines(c(cx,cx),c(cy,cy-487)); lines(c(cx,cx),c(cy,cy+487));
lines(c(cx,cx+487*cos(0)),c(cy,cy+487*sin(0)));
lines(c(cx,cx+487*cos(pi)),c(cy,cy+487*sin(pi)))
    if (jdis>0){
      segments(RULx,RULy,ROLx,ROLy)
      segments(RURx,RURy,RORx,RORy)
      segments(RULx,RULy,RURx,RURy)
      segments(ROLx,ROLy,RORx,RORy)
    }
    text(min(z[,id+1]),min(z[,id+2]),paste("fly",i))
    #---

        # define plot title
    if (jdis==0) {mainstr="sector distribution in frames"} else {
      mainstr=paste("sector distribution in frames",sttoffvec[jdis]/
60, "sec. after leaving CS till", endoffvec[jdis]/60, "sec.")}

    # histogramm of sector data
    strmain=
    hist(sec[intrvl], breaks=c(0.5,1.5,2.5,3.5,4.5),
main=paste("fly",i,mainstr),col=c("black", "red", "green", "blue"))

    if (jdis==length(sttoffvec)){
      plot(z[(zuerstrausCS:targetsec), id+1],
z[(zuerstrausCS:targetsec), id+2], pch=10, col="black", cex=0.5,
xlab="x", ylab="y", xlim=c(0,1288), ylim=c(0,996), main=paste("path
to target sec"), ann=FALSE, axes=FALSE)
      lines(c(cx,cx),c(cy,cy-487)); lines(c(cx,cx),c(cy,cy+487));
lines(c(cx,cx+487*cos(0)),c(cy,cy+487*sin(0)));
lines(c(cx,cx+487*cos(pi)),c(cy,cy+487*sin(pi)))
      segments(RULx,RULy,ROLx,ROLy); segments(RURx,RURy,RORx,RORy);
segments(RULx,RULy,RURx,RURy); segments(ROLx,ROLy,RORx,RORy)
      text(min(z[,id+1]),min(z[,id+2]),paste("fly",i))
    }


    # end of graphical output
```

```
####################################################################
  }

  # collect data for output data frame
  d<-rbind(d,c(alldis, ymat[1,], ymat[2,], ymat[3,], ymat[4,],
ymat[5,], ymat[6,], ymat[7,], zuerstin1, zuerstin2, zuerstin3,
zuerstin4,q))
}

# close pdf file
dev.off()

# reset R output
sink()

# write output data frame to file
# define row names in dataout
rownames(d)<-c("fly0")

# define column names in dataout
colnames(d)<-c("Distribution Sec1", "Distribution Sec2",
"Distribution Sec3", "Distribution Sec4","Distribution Sec1 30s",
"Distribution Sec2 30s", "Distribution Sec3 30s", "Distribution Sec4
30s","Distribution Sec1 60s", "Distribution Sec2 60s", "Distribution
Sec3 60s", "Distribution Sec4 60s","Distribution Sec1 90s",
"Distribution Sec2 90s", "Distribution Sec3 90s", "Distribution Sec4
90s","Distribution Sec1 120s", "Distribution Sec2 120s",
"Distribution Sec3 120s", "Distribution Sec4 120s","Distribution
Sec1 30s_60s", "Distribution Sec2 30s_60s", "Distribution Sec3
30s_60s", "Distribution Sec4 30s_60s","Distribution Sec1 30s_90s",
"Distribution Sec2 30s_90s", "Distribution Sec3 30s_90s",
"Distribution Sec4 30s_90s", "n12", "n21", "n23", "n32", "n13",
"n31","n14", "n41", "n24", "n42", "n34", "n43", "n12 30s", "n21
30s", "n23 30s", "n32 30s", "n13 30s", "n31 30s","n14 30s", "n41
30s", "n24 30s", "n42 30s", "n34 30s", "n43 30s","n12 60s", "n21
60s", "n23 60s", "n32 60s", "n13 60s", "n31 60s","n14 60s", "n41
60s", "n24 60s", "n42 60s", "n34 60s", "n43 60s", "n12 90s", "n21
90s", "n23 90s", "n32 90s", "n13 90s", "n31 90s","n14 90s", "n41
90s", "n24 90s", "n42 90s", "n34 90s", "n43 90s","n12 120s", "n21
120s", "n23 120s", "n32 120s", "n13 120s", "n31 120s","n14 120s",
"n41 120s", "n24 120s", "n42 120s", "n34 120s", "n43 120s","n12
30-60s", "n21 30-60s", "n23 30-60s", "n32 30-60s", "n13 30-60s",
"n31 30-60s","n14 30-60s", "n41 30-60s", "n24 30-60s", "n42 30-60s",
"n34 30-60s", "n43 30-60s","n12 30-90s", "n21 30-90s", "n23 30-90s",
"n32 30-90s", "n13 30-90s", "n31 30-90s","n14 30-90s", "n41 30-90s",
"n24 30-90s", "n42 30-90s", "n34 30-90s", "n43 30-90s","First in 1",
"First in 2", "First in 3", "First in 4", "frames to target sec")

# write data to file
write.csv(d,
file="RDataOutput.csv")#########################################

#-----------------
```