# The TOPPE driver/interpreter for GE scanners (toppev2.e)

This document applies to version 2.0 of the pulse sequence (toppev2.e). Tested on a GE Discovery MR750 scanner running software version DV26.

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https://toppemri.github.io/

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# **Chapter 1**

# Source files

#### 1.1 Introduction

This white paper provides a high-level description of the EPIC source code for the TOPPE driver of the TOPPE file format, suitable for distribution to the public (i.e., no EPIC-specific information is revealed here, as such information is reserved for research sites with access to the EPIC compiler).

The main source files for the TOPPE driver (for GE scanners) are:

jfn\_rf\_files2.c, jfn\_rf\_files2.h

Defines a C structure ('rfstruct') containing all information pertaining to one module (i.e., one .mod file), including header info and the waveforms themselves. Also defines associated helper functions for reading a .mod file, managing waveform memory, etc.

cores.c, cores.h

Defines a C struct and associated helper functions for loading information from modules.txt. Also contains a function for reading scanloop.txt.

toppev2.e

Main EPIC file. Loads scanloop.txt, modules.txt, and the .mod files (listed in modules.txt), using the helper functions in the above .c/.h files. Executes sequence on the scanner, by stepping through each line in scanloop.txt in sequential order.

# **1.2** jfn\_rf\_files2.c and jfn\_rf\_files2.h

These files were originally used to load RF waveforms, hence the 'rf' in the file name. However, these files are now used to load .mod files regardless of whether they will be used for RF excitation, data readout, or only for playing out gradient waveforms (for, e.g., gradient spoiling or diffusion-encoding). This allows for a compact code base, and for flexibility in using a .mod file for several purposes; for example, the gradients associated with an RF excitation module can be used as readout waveforms during a gradient trajectory mapping experiment using the Duyn method.

```
/* jfn_rf_files2.h */
typedef struct {
   char fname[80];
                                /* rf file name */
   short ncoils;
                                 /* number of coils/channels */
   short npre;
                                 /\star number of points before start of rf waveform \star/
  short rfres;
                               /* number of points in rf waveform */
/* number of points in gradient waveform (>= rfres) */
  short res;
  short npulses;
                                 /* number of different waveforms in .wav file */
  float blmax;
                                 /* Gauss */
  float gmax;
short dataoffset;
                                 /* Gauss/cm (4.0 on um3t) */
                                 /* total header size (including ASCII and binary parts) */
  short nparamsint16;
                                 /* # of int16 parameters */
  short nparamsfloat; /* # of float parameters */
short paramsint16[32]; /* int16 parameters */
float paramsfloat[32]; /* float parameters */
   short*** rho;
   short*** theta;
   short** gx;
   short** gy;
   short ** gz;
} rfstruct;
int jfn_rf_getfilename(char *fname, int index, const char* directory);
int jfn_rf_readheader(char *fname, rfstruct *rfinfo);
int jfn_rf_allocatemem(rfstruct *rfinfo);
int jfn_rf_readwaveforms(rfstruct *rfinfo, int ishard);
int jfn_rf_freemem(rfstruct *rfinfo);
int readshort(short* i, int n, FILE* fid);
```

```
/* jfn_rf_files2.c */
#include <string.h>
#include <math.h>
#include "jfn_globaldefs.h"
#include "jfn_rf_files2.h"
/* get name of rf file from the names listed in 'rffiles.txt' */
int jfn_rf_getfilename(char *fname, int index, const char* directory) {
    char tmpfname[80];
    int i;
   FILE *fid;
    sprintf(tmpfname, "%srffiles.txt", directory);
    if ((fid = fopen (tmpfname, "r")) == NULL)
        return(JFN_FAILURE);
    for (i = 0; i<index; i++)</pre>
        fscanf(fid, "%s\n", tmpfname);
   fscanf(fid, "%s\n", fname);
    fclose (fid);
    return JFN_SUCCESS;
```

```
}
short orderbyte(short in)
#ifdef LITTLE_ENDIAN
 char* sw;
 char tmp;
 sw = (char*)∈
 tmp=sw[0];
 sw[0] = sw[1];
 sw[1] = tmp;
 /*
 in = htons(in);
 */
#endif
return in;
unsigned short orderbyteu (unsigned short in)
#ifdef LITTLE_ENDIAN
 char* sw;
 char tmp;
 sw = (char*)∈
 tmp=sw[0];
 sw[0] = sw[1];
 sw[1] = tmp;
 /*
 in = htons(in);
 */
#endif
 return in;
int jfn_rf_readheader(char *fname, rfstruct *rfinfo)
   FILE *fid;
   short nchar;
   int i;
   fprintf(stderr,"jfn_rf_readheader(): reading %s \n", fname);
   strcpy(rfinfo->fname, fname);
   if ((fid = fopen (fname, "r")) == NULL)
       return(JFN_FAILURE);
    /* go past ascii description */
    fread(&nchar, sizeof(short), (int) 1, fid);
   nchar = orderbyte(nchar);
   fseek(fid, nchar, SEEK_CUR);
    /* read rest of header */
```

```
readshort(&(rfinfo->ncoils), 1, fid);
   readshort(&(rfinfo->res),
                                 1, fid) ;
   readshort(&(rfinfo->npulses), 1, fid);
    fscanf(fid, "blmax: %f\n", &(rfinfo->blmax));
    fscanf(fid, "gmax: %f\n", &(rfinfo->gmax));
    fprintf(stderr, "\trfinfo.ncoils = %d \n", rfinfo->ncoils);
    fprintf(stderr, "\trfinfo.res = %d \n", rfinfo->res);
    fprintf(stderr, "\trfinfo.npulses = %d \n", rfinfo->npulses);
   readshort(&(rfinfo->nparamsint16), 1, fid);
   readshort(rfinfo->paramsint16, rfinfo->nparamsint16, fid);
   rfinfo->npre = rfinfo->paramsint16[0];
   rfinfo->rfres = rfinfo->paramsint16[1];
   readshort (& (rfinfo->nparamsfloat), 1, fid);
   for (i = 0; i < rfinfo->nparamsfloat; i++) {
        fscanf(fid, "%f\n", &(rfinfo->paramsfloat[i]));
   rfinfo->dataoffset = ftell(fid);
   fclose (fid);
   return JFN_SUCCESS;
}
int readshort(short* i, int n, FILE *fid) {
   int j;
   fread(i, sizeof(short), n, fid);
   for (j=0; j<n; j++)</pre>
       i[j] = orderbyte(i[j]);
   return JFN_SUCCESS;
}
int readushort(unsigned short *i, int n, FILE *fid) {
   int j;
    fread(i, sizeof(unsigned short), n, fid);
   for (j=0; j<n; j++)</pre>
        i[j] = orderbyteu(i[j]);
   return JFN_SUCCESS;
int jfn_rf_readwaveforms(rfstruct *rfinfo, int ishard)
   FILE *fid;
               /* p = pulse number (0 or 1), c = coil #, i = waveform point index \star/
   int p,c,i;
   int maxiamp = 32766;
```

```
if ((fid = fopen (rfinfo->fname, "r")) == NULL)
       return(JFN_FAILURE);
    /* go past ascii and binary header */
   fseek (fid, rfinfo->dataoffset, SEEK_SET);
    /\star read waveforms. Note that we're only using rf channel 1 in the psd itself. \star/
    for (p = 0; p < rfinfo->npulses; p++) {
        for (c = 0; c < rfinfo->ncoils; c++)
           readshort(rfinfo->rho[p][c], (int) rfinfo->res, fid);
        for (c = 0; c < rfinfo->ncoils; c++)
            readshort(rfinfo->theta[p][c], (int) rfinfo->res, fid);
        readshort(rfinfo->gx[p], (int) rfinfo->res, fid) ;
        readshort(rfinfo->gy[p], (int) rfinfo->res, fid) ;
        readshort(rfinfo->gz[p], (int) rfinfo->res, fid);
    }
    /* set to hard pulse if selected */
   if (ishard) {
        for (p = 0; p < rfinfo->npulses; p++) {
            for (c = 0; c < rfinfo \rightarrow ncoils; c++)
                for (i = 0; i < rfinfo->res; i++) {
                    rfinfo->rho[p][c][i] = (short) maxiamp;
                    rfinfo->theta[p][c][i] = (short) 0;
                }
            }
        }
   }
    /* make sure EOS bit of last point is set */
   for (p = 0; p < rfinfo->npulses; p++) {
        for (c = 0; c < rfinfo \rightarrow ncoils; c++) {
            if (!(rfinfo->rho[p][c][rfinfo->res-1] % 2))
                rfinfo->rho[p][c][rfinfo->res-1]++;
            if (!(rfinfo->theta[p][c][rfinfo->res-1] % 2))
                rfinfo->theta[p][c][rfinfo->res-1]++;
        if (!(rfinfo->gx[p][rfinfo->res-1] % 2))
           rfinfo->gx[p][rfinfo->res-1]++;
        if (!(rfinfo->gy[p][rfinfo->res-1] % 2))
            rfinfo->gy[p][rfinfo->res-1]++;
        if (!(rfinfo->gz[p][rfinfo->res-1] % 2))
            rfinfo->gz[p][rfinfo->res-1]++;
    }
    fclose (fid);
    return JFN_SUCCESS;
/* allocate memory for waveforms */
int jfn_rf_allocatemem(rfstruct *rfinfo) {
    int p,c;
   int npulses = rfinfo->npulses;
    rfinfo->rho = (short***)AllocNode(sizeof(short**)*npulses);
    rfinfo->theta = (short***)AllocNode(sizeof(short**)*npulses);
```

```
rfinfo->gx = (short**)AllocNode(sizeof(short*)*npulses);
    rfinfo->gy = (short**)AllocNode(sizeof(short*)*npulses);
   rfinfo->gz = (short**)AllocNode(sizeof(short*)*npulses);
    for (p = 0; p < npulses; p++) {
        rfinfo->rho[p] = (short**)AllocNode(sizeof(short*)*rfinfo->ncoils);
       rfinfo->theta[p] = (short**)AllocNode(sizeof(short*)*rfinfo->ncoils);
        for (c=0; c < rfinfo->ncoils; c++) {
            rfinfo->rho[p][c] = (short*)AllocNode(sizeof(short)*rfinfo->res);
            rfinfo->theta[p][c] = (short*)AllocNode(sizeof(short)*rfinfo->res);
        rfinfo->gx[p] = (short*)AllocNode(sizeof(short)*rfinfo->res);
       rfinfo->gy[p] = (short*)AllocNode(sizeof(short)*rfinfo->res);
       rfinfo->gz[p] = (short*)AllocNode(sizeof(short)*rfinfo->res);
    }
   return JFN_SUCCESS;
}
/* free memory */
int jfn_rf_freemem(rfstruct *rfinfo) {
    int p,c;
   int npulses = rfinfo->npulses;
    for (p = 0; p < npulses; p++) {</pre>
       FreeNode(rfinfo->qz[p]);
       FreeNode(rfinfo->gy[p]);
       FreeNode(rfinfo->gx[p]);
        for (c=0; c < rfinfo->ncoils; c++) {
           FreeNode(rfinfo->rho[p][c]);
           FreeNode(rfinfo->theta[p][c]);
       FreeNode(rfinfo->theta[p]);
       FreeNode(rfinfo->rho[p]);
   }
   FreeNode(rfinfo->gz);
   FreeNode(rfinfo->gy);
   FreeNode(rfinfo->gx);
   FreeNode(rfinfo->theta);
   FreeNode (rfinfo->rho);
    return JFN_SUCCESS;
```

## 1.3 cores.c, cores.h

```
/* cores.c */
#include "cores.h"
#include "jfn_rf_files2.h" /* need readshort() etc */
int cores_getinfo(char *fname, corestruct* coredefinfo) {
   FILE *fid;
   short nchar, tmp;
   int i;
   char line[200];
   fprintf(stderr, "cores_getinfo(): reading %s \n", fname);
   if ((fid = fopen (fname, "r")) == NULL)
       return(JFN_FAILURE);
   fgets(&line, 200, fid); /* skip line */
    fscanf(fid, "%d\n", &(coredefinfo->ncores));
   fgets(&line, 200, fid); /* skip line */
   coredefinfo->wavfiles = (char**)AllocNode(sizeof(char*)*(coredefinfo->ncores));
   coredefinfo->dur = (int*)AllocNode(sizeof(int)*(coredefinfo->ncores));
   coredefinfo->hasRF = (int*)AllocNode(sizeof(int)*(coredefinfo->ncores));
   coredefinfo->hasDAQ = (int*)AllocNode(sizeof(int)*(coredefinfo->ncores));
   for (i = 0; i < coredefinfo->ncores; i++) {
        coredefinfo->wavfiles[i] = (char*)AllocNode(sizeof(char)*100);
        fscanf(fid, "%s\t%d\t%d\t",
           coredefinfo->wavfiles[i],
           &(coredefinfo->dur[i]),
           &(coredefinfo->hasRF[i]),
            &(coredefinfo->hasDAQ[i]));
        fprintf(stderr, "cores_getinfo(): %s\t%d\t%d\t%d\n",
           coredefinfo->wavfiles[i],
           coredefinfo->dur[i],
           coredefinfo->hasRF[i],
           coredefinfo->hasDAQ[i]);
   }
   fclose (fid);
   return JFN_SUCCESS;
}
/* free memory */
int cores_freemem(corestruct *coredefinfo) {
```

```
int i,c;
   int ncores = coredefinfo->ncores;
   FreeNode(coredefinfo->dur);
   FreeNode(coredefinfo->hasRF);
   FreeNode (coredefinfo->hasDAQ);
   for (i = 0; i < ncores; i++) {</pre>
       FreeNode(coredefinfo->wavfiles[i]);
   FreeNode(coredefinfo->wavfiles);
   return JFN_SUCCESS;
}
int cores_getloophdr(char *fname, int* loophdr) {
   FILE *fid;
   int nt, i;
   char line[200];
   fprintf(stderr, "cores_getloophdr(): reading %s \n", fname);
   if ((fid = fopen (fname, "r")) == NULL)
       return(JFN_FAILURE);
   fgets(&line, 200, fid); /* go past first line */
   fprintf(stderr, "\tcores_getloophdr: Found %d startseq() calls in loop file\n", loophdr[0]);
   fclose (fid);
   return JFN_SUCCESS;
}
/* read .loop file */
int cores_readloop(char *fname, int* looparr) {
   FILE *fid;
   int nt, i, j;
   char line[200];
   int loophdr[4];
   fprintf(stderr, "cores_readloop(): reading %s \n", fname);
   if ((fid = fopen (fname, "r")) == NULL)
       return(JFN_FAILURE);
   fgets(&line, 200, fid);
                          /* skip line */
   fscanf(fid, "%d\t%d\t%d\t", &(loophdr[0]), &(loophdr[1]), &(loophdr[2]), &(loophdr[3]));
   nt = loophdr[0];
   fgets(&line, 200, fid); /* skip line */
   /* load loop array */
   for (i = 0; i < nt; i++) {</pre>
```

## 1.4 toppev2.e

toppev2.e is written in EPIC, a proprietary C-based programming language developed by GE, and can therefore not be listed in full here <sup>1</sup>. Only code excerpts are presented here.

### 1.4.1 Loading modules.txt

Prior to scanning, toppev2.e first reads modules.txt:

```
#define MAXCORES 20 /* determined empirically */
corestruct coredefinfo; /* contains list of .mod files and related info */
int hasRF[MAXCORES];
int hasDAQ[MAXCORES];
int coredur[MAXCORES];

/* get total number of unique modules/cores, and fill hasDAQ and hasRF arrays */
cores_getinfo("modules.txt", &coredefinfo);
ncores = coredefinfo.ncores;
for (j=0; j<ncores; j++) {
   hasRF[j] = coredefinfo.hasRF[j];
   hasDAQ[j] = coredefinfo.hasDAQ[j];
}</pre>
```

At this point, coredefinfo also contains a list of .mod file names.

<sup>&</sup>lt;sup>1</sup>For access to toppev2.e, see https://toppemri.github.io/

#### 1.4.2 Miscellaneous sequence information

Miscellaneous other information is also loaded early on during sequence prescription. For example, the number of samples to acquire (per readout) is loaded from readout.mod:

#### 1.4.3 Loading waveform shapes

toppev2.e then loads all waveforms for the .mod files contained in the coredefinfo struct:

```
rfstruct* coresinfo; /* array of rfstruct (.mod file info) for array of cores */
coresinfo = (rfstruct *) AllocNode(ncores*sizeof(rfstruct));

for ( j=0; j<ncores; j++ ) {

    /* read and load .mod file for core j */
    jfn_rf_readheader(coredefinfo.wavfiles[j], &coresinfo[j]);
    jfn_rf_allocatemem(&coresinfo[j]);
    jfn_rf_readwaveforms(&coresinfo[j], ishard);</pre>
```

The struct array coresinfo now contains all sequence waveforms, for all modules.

The waveforms are then moved to sequence hardware, using EPIC functions (not shown).

#### 1.4.4 Loading scanloop.txt

The final task before executing the sequence is to load the scan loop description:

```
int looparr[9000000];  /* scan loop definition, loaded from scanloop.txt */

/* get scan loop header info */
cores_getloophdr("scanloop.txt", loophdr);
nstartseq = loophdr[0];  /* number of rows */
maxslice = loophdr[1];
maxecho = loophdr[2];
maxview = loophdr[3];

/* fill looparr (needed in scan()) */
cores_readloop("scanloop.txt", looparr);
```

The scan loop information is now stored in the 2D array looparr.

See the TOPPE user guide for a detailed description of scanloop.txt.

## 1.4.5 Sequence execution

toppev2.e "simply" steps through each row in looparr, and executes the waveforms (RF and gradient) associated with the module indexed by the first column (modules are numbered in the order of appearance in modules.txt). Each line corresponds to the execution of one .mod file.