

Wavenology SQIF Demo

2014-07

Content

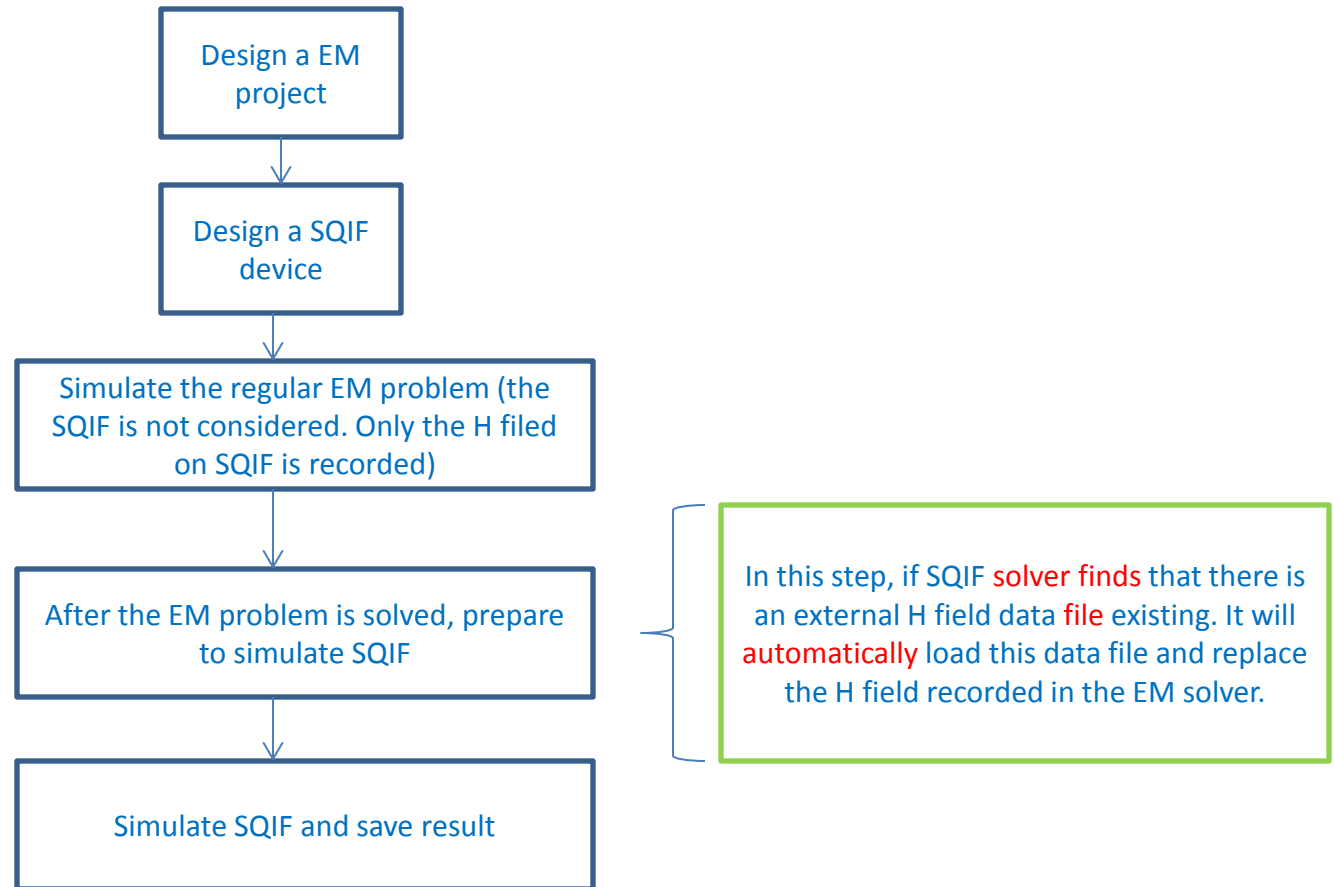
1. Demo cases

1. Pure 1D Serial SQIF with user input magnetic flux
 - Show how to simulate a 1D serial SQIF and how to obtain the DC voltage response of a SQIF
2. Pure 1D Parallel SQIF with user input magnetic flux
 - Show how to simulate a 1D parallel SQIF and how to obtain the DC voltage response of a SQIF
3. Single loop dc SQUID with user input magnetic flux
 - Show how to simulate a dc SQUID and how to obtain the DC voltage response of a SQUID
4. 1D Serial SQIF with plane wave incident
 - Show how to co-simulate SQIF and a regular EM problem
5. 2D SQIF simulation with plane wave incident and dipole antenna
 - Show how to co-simulate SQIF with antenna and other sources

2. Procedure of building a SQIF and simulation problem

- The example is “2D SQIF simulation with plane wave incident and dipole antenna”

Basic SQIF simulation scheme



Note: the external H field file must be in the same folder of project file, with a **fixed name** "SQIF_input.txt".

This means that, if user want to use external H field file, each project should have it's own folder. There cannot be multiple "SQIF_input.txt" existing for different projects in one folder, except all projects will use the same H field.

Example of the External H Field File

- Case file: SQIF\demo\1D SQIF\serial\dc_voltage_response\40-loop-gaussian-s\SQIF_input.txt

```
1
0 0
10e-12 -41.18e0
1e-9 -41.18e0
61e-9 41.18e0
```

2 columns data

File format type is 1, means the data in this file is H field. All loops in the array will use the same H field.

The data will be represented by 2 columns. The 1st column is time in second. The 2nd column is the H field magnitude in A/m.

Here, we can see the H field is in the range of +/-41.18 A/m. Therefore, the equivalent magnetic flux quantum through a 200 μm^2 loop is:

$$u_0 H S / \Phi_0 = 4\pi e^{-7} * 41.18 * 200e^{-12} / 2.0678e^{-15} = 5$$

As the flux plot in the case 1.

Simulation Time Step Control

There are two kinds of SQUID simulation setup. One is using text format Spice circuit. Another is using WCT graphic circuit editor (GUI).

➤ **Text format Spice circuit:** user can control the time step directly by Spice instruction, which is in the line “.tran xxxx”, for example, “.tran 2p 61ns 0s **2p** uic”. Here, the **2p** in red is the maximum delta time (Δt) in the SQIF simulation. More detail information please refer to the Spice manual in the following link:

<http://newton.ex.ac.uk/teaching/CDHW/Electronics2/userguide/sec4.html>

subsection “4.3.9 .TRAN: Transient Analysis”

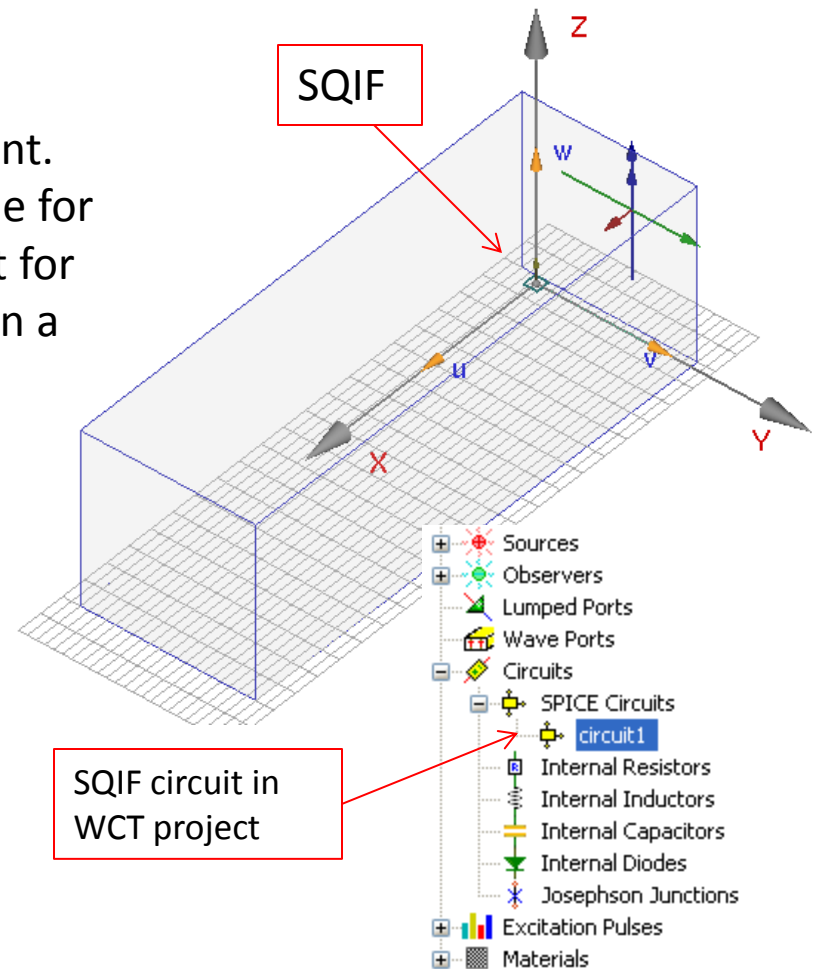
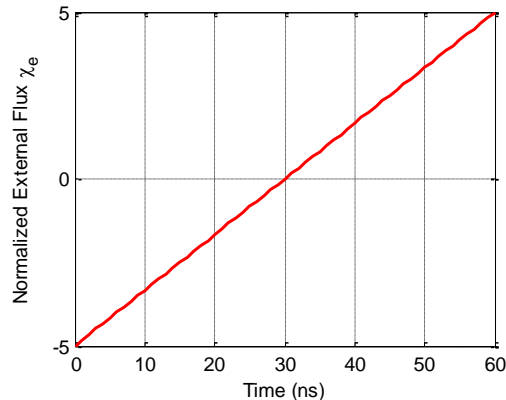
➤ For **GUI type** of simulation project, currently, there is not place to let user input time control in the circuit. So, we use Δt of the project automatically. The setting page is in the **Time** Tab of project design, as shown in the right-bottom figure of Page 36. In general, full wave EM solver will use a much smaller Δt compared to the Δt requirement in a SQIF simulation.

1. It is suggested to use “Text format Spice circuit” to simulate SQUID/SQIF.
2. According to our experience, it is suggested that the Δt in SQIF simulation will not larger than 6ps. A smaller Δt will have better accuracy, but cause longer simulation time. We find that, for most cases, **2p second** will bring a good balance for accuracy and shorter simulation time.

Case 1: Pure 1D Serial SQIF with user input magnetic flux

- Case file: SQIF\demo\1D SQIF\serial\dc_voltage_response\40-loop-gaussian-s\s40_I1_Im.wnt
- This case is used to show how to obtain **the dc voltage response** on a 40 loops 1D serial dc SQIF

This case looks like using a plane wave incident. However, we define an external H field data file for SQIF. This data will be the actual H field input for SQIF. Following figure is the equivalent flux on a loop with $200 \mu\text{m}^2$.



Full SQIF circuit Setting

(note: This case we use TEXT format circuit. However, WCT also support graphic format circuit, it can be also used to build a SQIF circuit)

The screenshot shows the 'Modify Lumped Circuit' dialog box with the following sections:

- General:** Name:
- Circuit Text:** A text area containing:

```
sqif
*bias current source
ib 0 100 PWL(0 0 0 001e-9 0 0 002e-9 0 2002e-3 1 0e-3 0 2002e-3)
x01 100 0 sqif 1
.tran 2p 60ns 0s 2p uic
.end
```

Annotations: A red box highlights the line `*bias current source` with the text "dc bias current" above it. A green box highlights the line `x01 100 0 sqif 1` with the text "SQIF" below it.
- Ports:** A table with columns: Node Pair, Start Position, End Position.
- Existing Subcircuits in Project:** A table with columns: type, name, parameter.
- System Intrinsic Subcircuits:** A panel with icons for 1D Sqif, 2D Sqif, and DC-Squid.

Node Pair	Start Position	End Position
1	1, 0	0, 0, 0
2		
3		
4		

type	name	parameter
1D SQIF	sqif1	Loops=40

System Intrinsic Subcircuits		
1D Sqif	2D Sqif	DC-Squid

Serial SQIF parameters

1D SQIF Editor

Name: sqif1 Layout: Serial

Loops Information

Loops No.: 40 Loops Area Distribution Type: User Defined

Formula:

Load Edit

Parameters: S0: K: A: t range: t0: 0 t1: 1

Parameters for each loop

Loop Center: User Input Edit

Loop Normal: Edit Identical

Josephson Junctions: Edit Identical

Self-inductance (H): Edit Proportional to area Factor: 0.015

Mutual-inductance (H): Edit Unit: Coupling factor

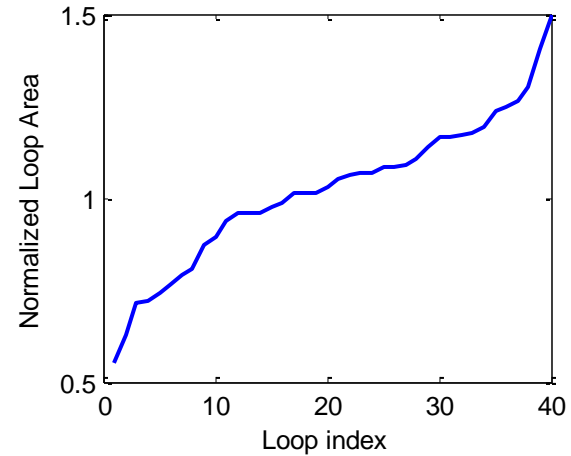
Bias DC current (A): Magn. Flux Density (B): 1 Type: Const

Miscellaneous

DC Bias H Field (A/m): 0 Startup Delay (s): 0

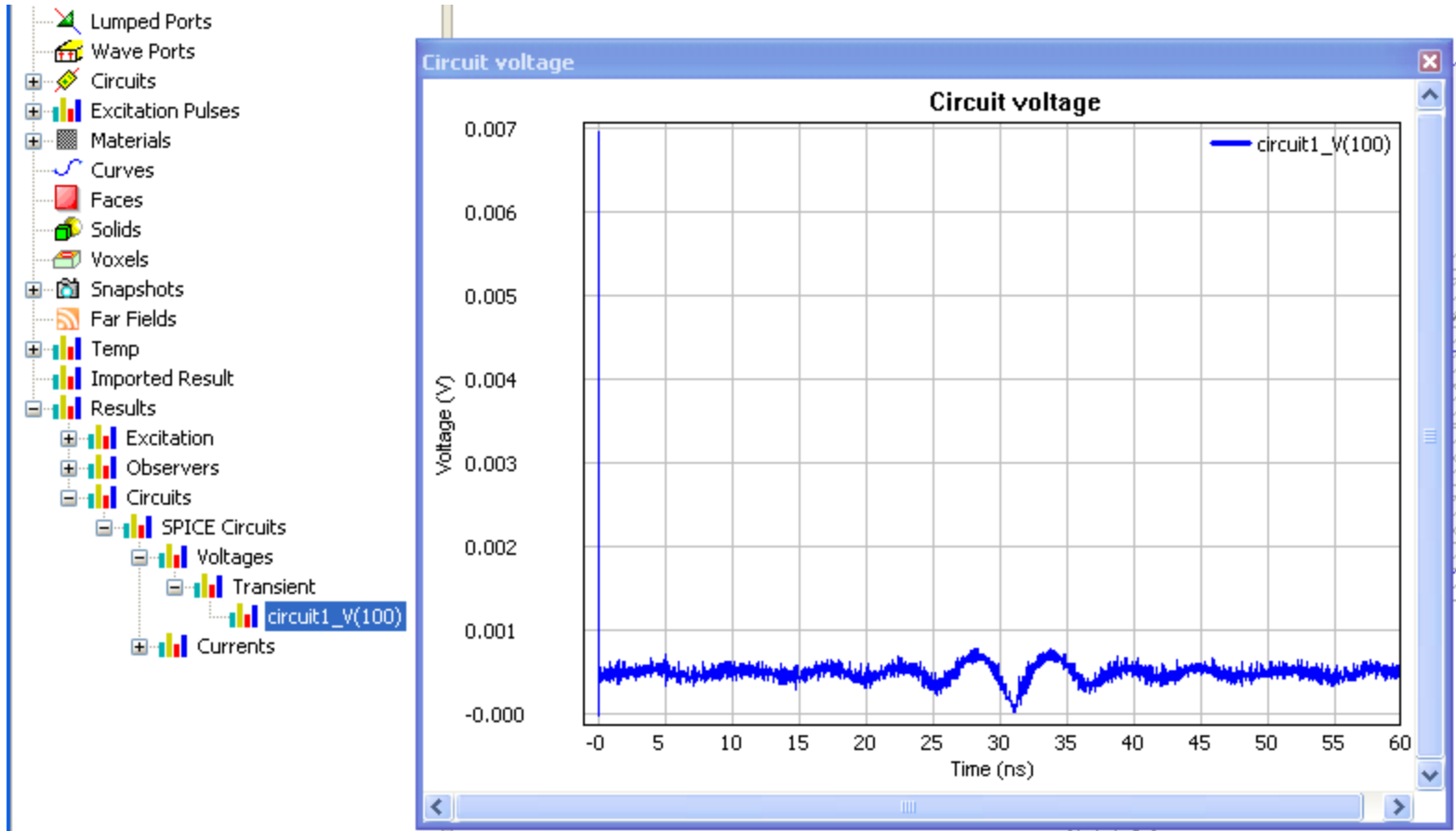
Help OK Cancel

Loops area
 $1=200 \mu\text{m}^2$

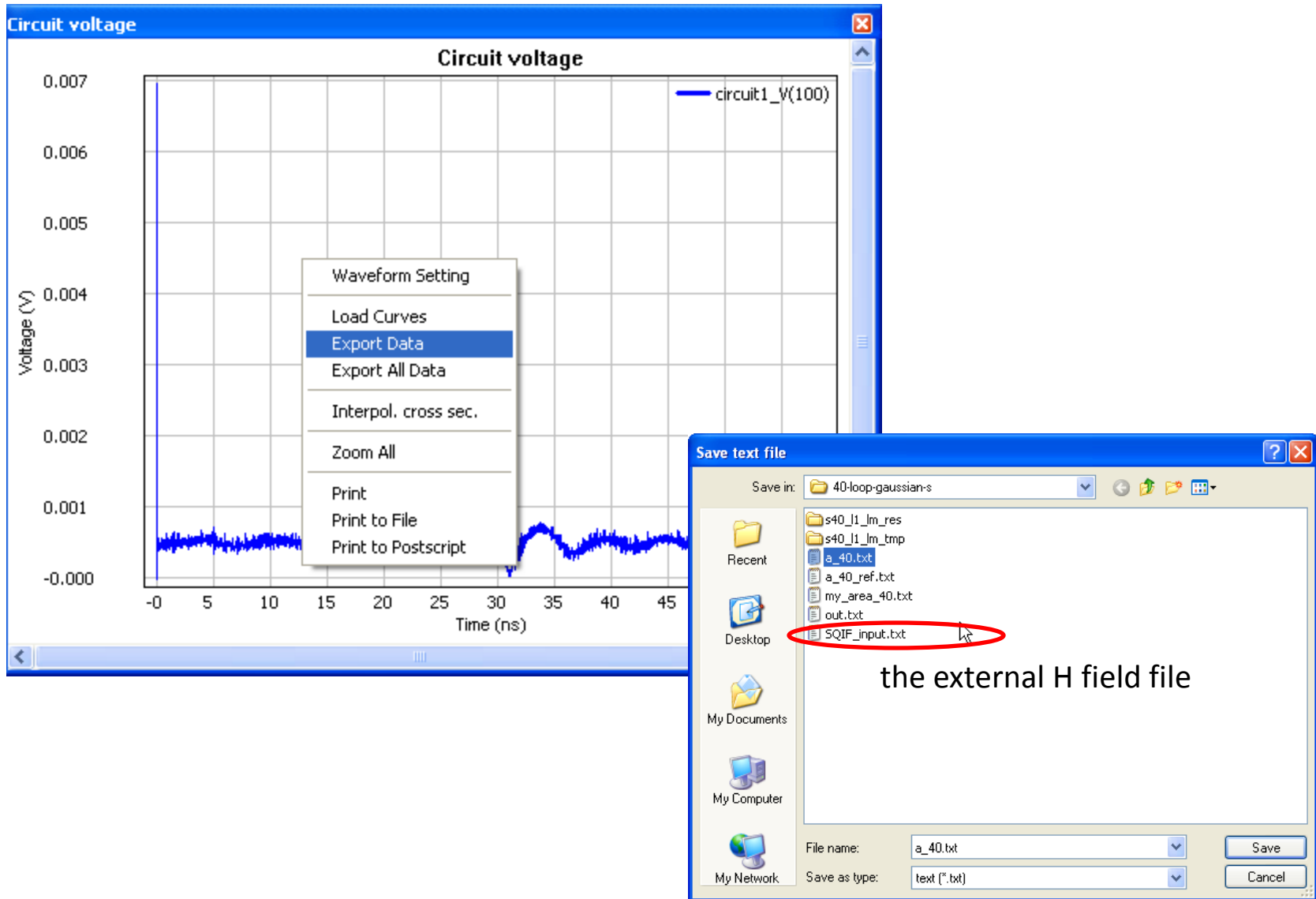


The loops size is imported from file:
[my_area_40.txt](#)

Transient output voltage of SQIF



Right click mouse to export this voltage data as “a_40.txt”

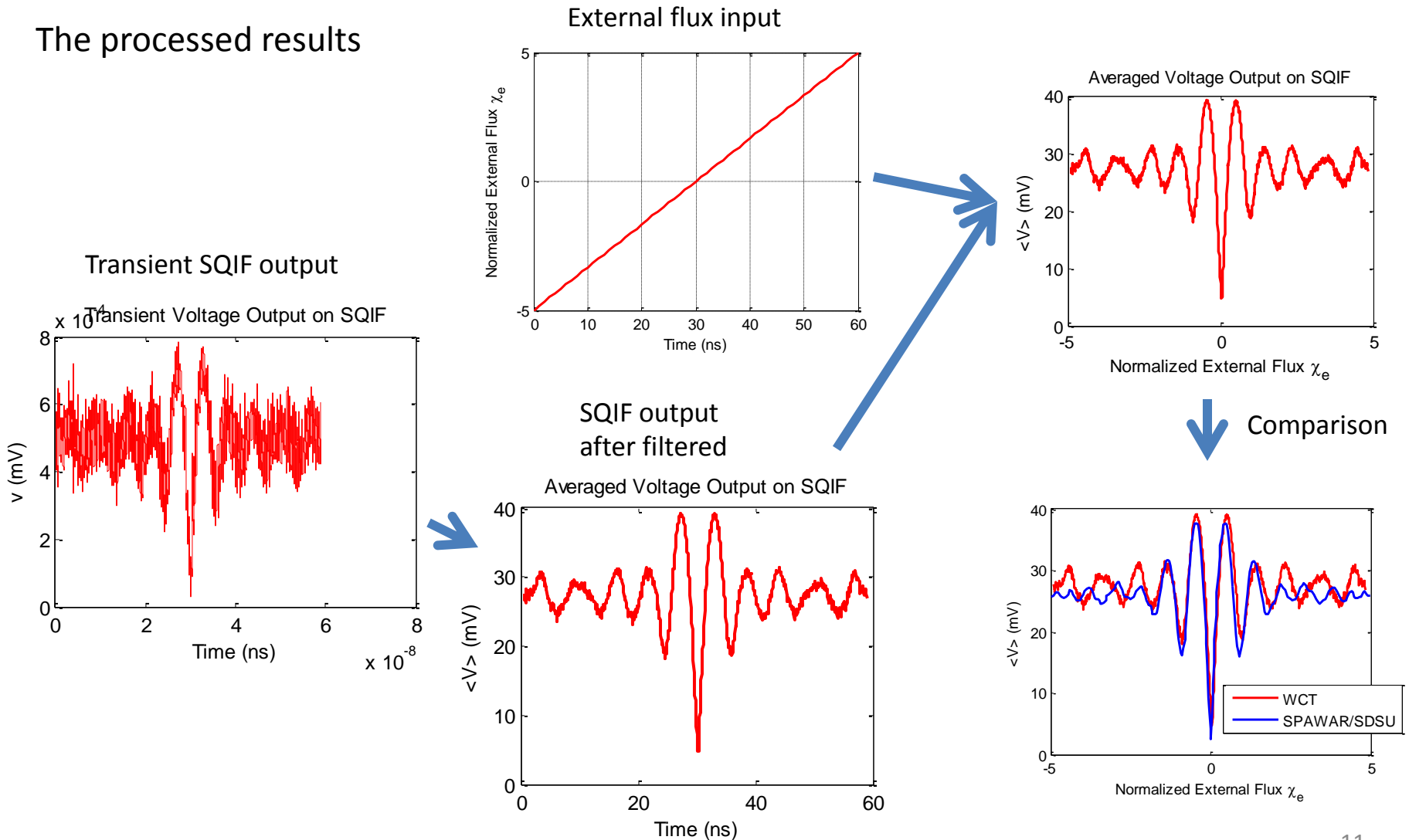


Use matlab code to filter this data to obtain the dc voltage response of SQIF.

The matlab code is under the WCT project folder as:

[SQIF\demo\1D SQIF\serial\dc_voltage_response\40-loop-gaussian-s\show_res_2.m](#)

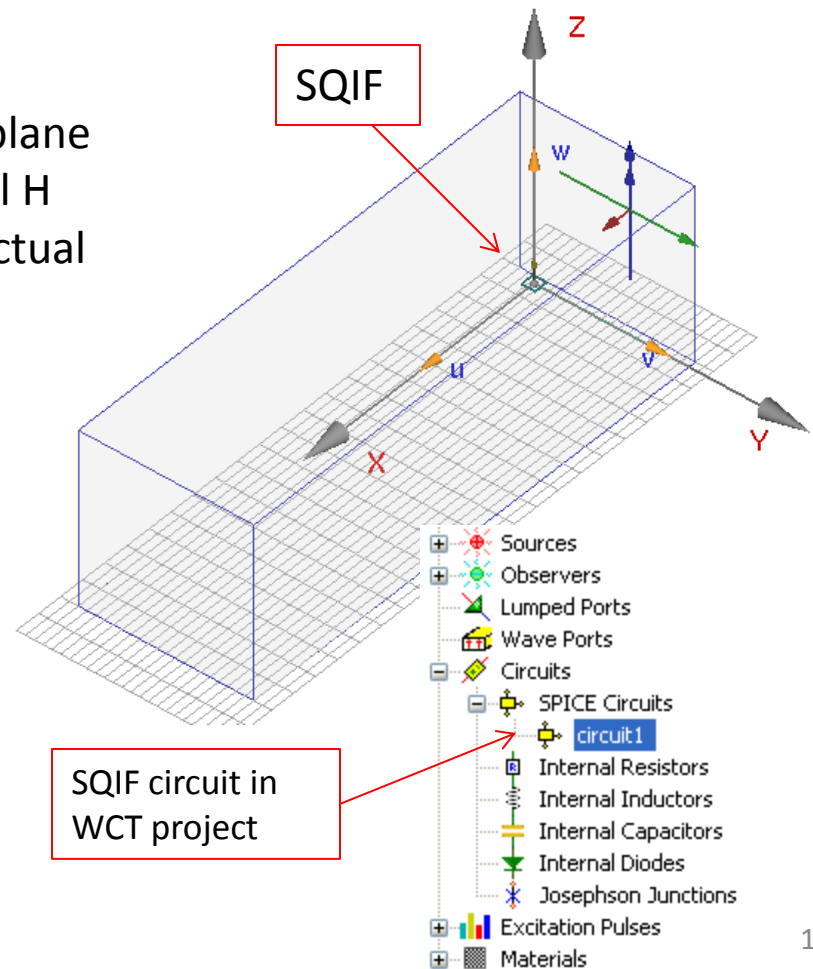
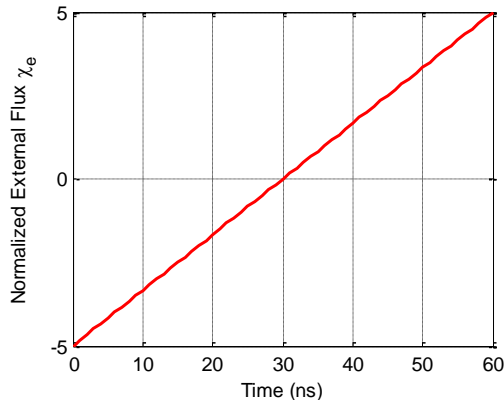
The processed results



Case 2: Pure 1D Parallel SQIF with user input magnetic flux

- Case file: SQIF\demo\1D SQIF\serial\dc_voltage_response\40-loop-gaussian-p\s40_l1_Im.wnt
- This case is used to show how to obtain **the dc voltage response** on a 40 loops 1D parallel dc SQIF

Similar to case 1, this case looks like using a plane wave incident. However, we define a external H field data file for SQIF. This data will be the actual H field input for SQIF. Following figure is the equivalent flux on a loop with $200 \mu\text{m}^2$.



Full SQIF circuit Setting

(note: This case we use TEXT format circuit. However, WCT also support graphic format circuit, it can be also used to build a SQIF circuit)

Modify Lumped Circuit

General
Name:

Circuit Text

```
sqif
*bias current source
ib 0 100 PWL(0,0,0,001e-9,0,0,002e-9,41,041e-4,1,0e-3,41,041e-4)
x01 100 0 sqif 1
.tran 2p 60ns 0s 2p uic
.end
```

dc bias current

SQIF

Existing Subcircuits in Project

type	name	parameter
1D SQIF	sqif1	Loops=40

Delete

System Intrinsic Subcircuits

1D Sqif 2D Sqif DC-Squid

Insert

Delete Reverse Position Help OK Cancel

Parallel SQIF parameters

Name: sqif1 Layout: Parallel

Loops Information

Loops No.: 40 Loops Area Distribution Type: User Defined

Formula:

Load Edit

Parameters: 50 K A

t range: t0: 0 t1: 1

Parameters for each loop

Loop Center: User Input

Loop Normal: Identical

Josephson Junctions: Identical

Self-inductance (H): Proportional to area Factor: 0.015

Mutual-inductance (H): Unit: Coupling factor

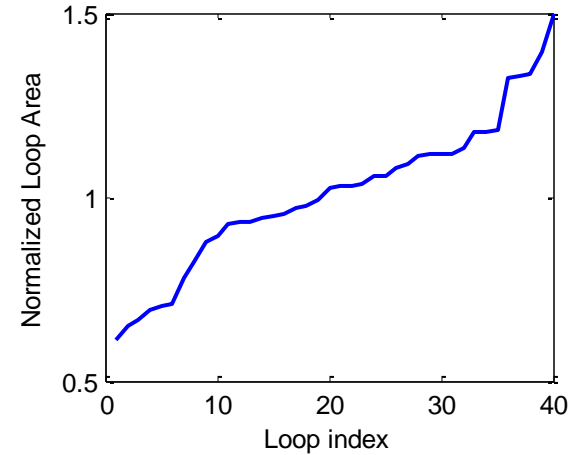
Bias DC current (A): Magn. Flux Density (B): 1 Type: Const

Miscellaneous

DC Bias H Field (A/m): 0 Startup Delay (s): 0

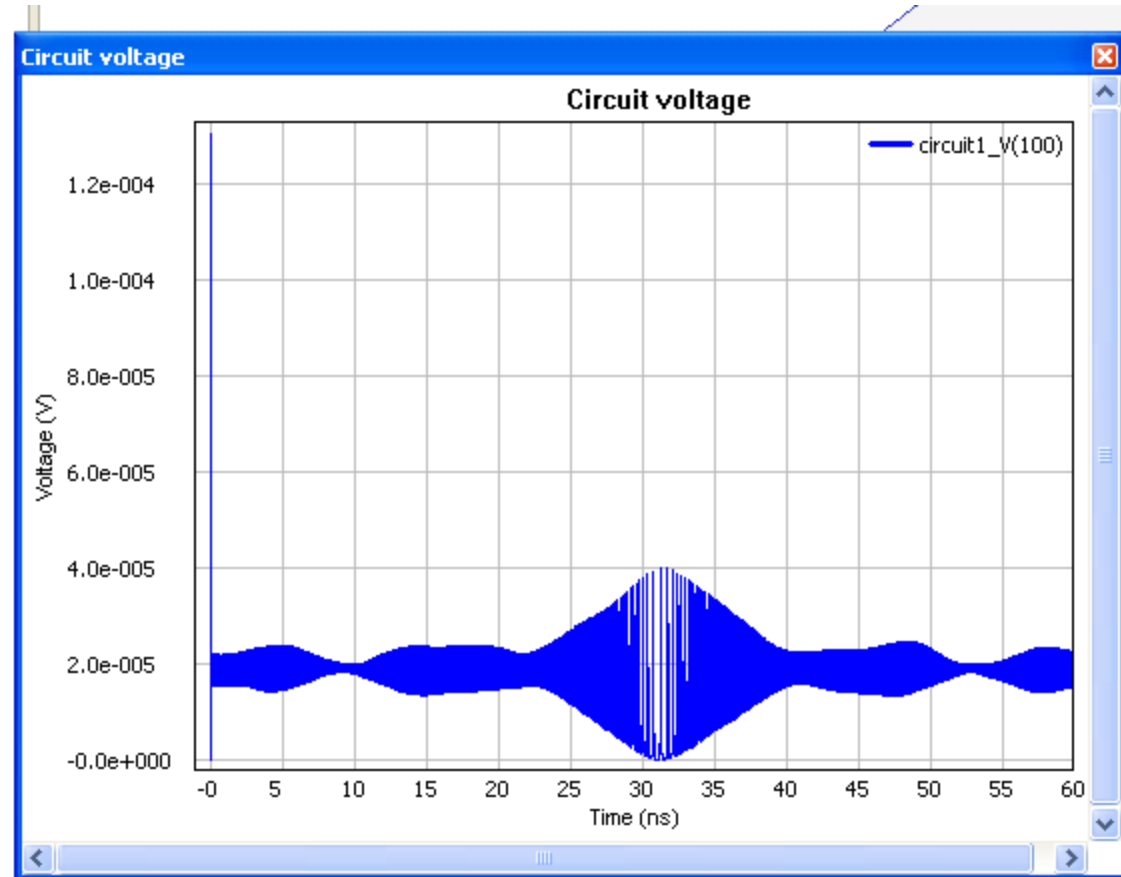
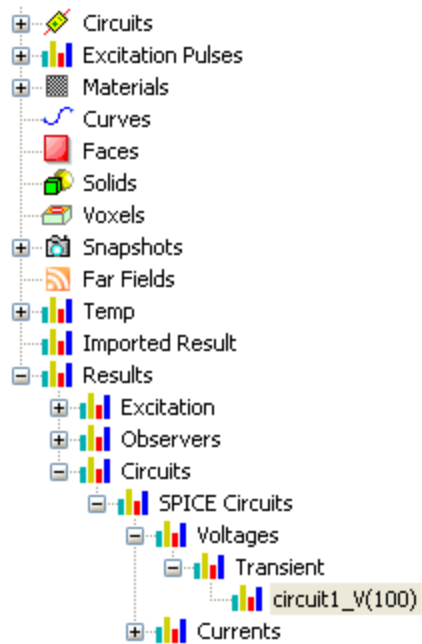
Help OK Cancel

Loops area
 $1=200 \mu\text{m}^2$



The loops size is imported from file:
[my_area_40.txt](#)

Transient output voltage of SQIF



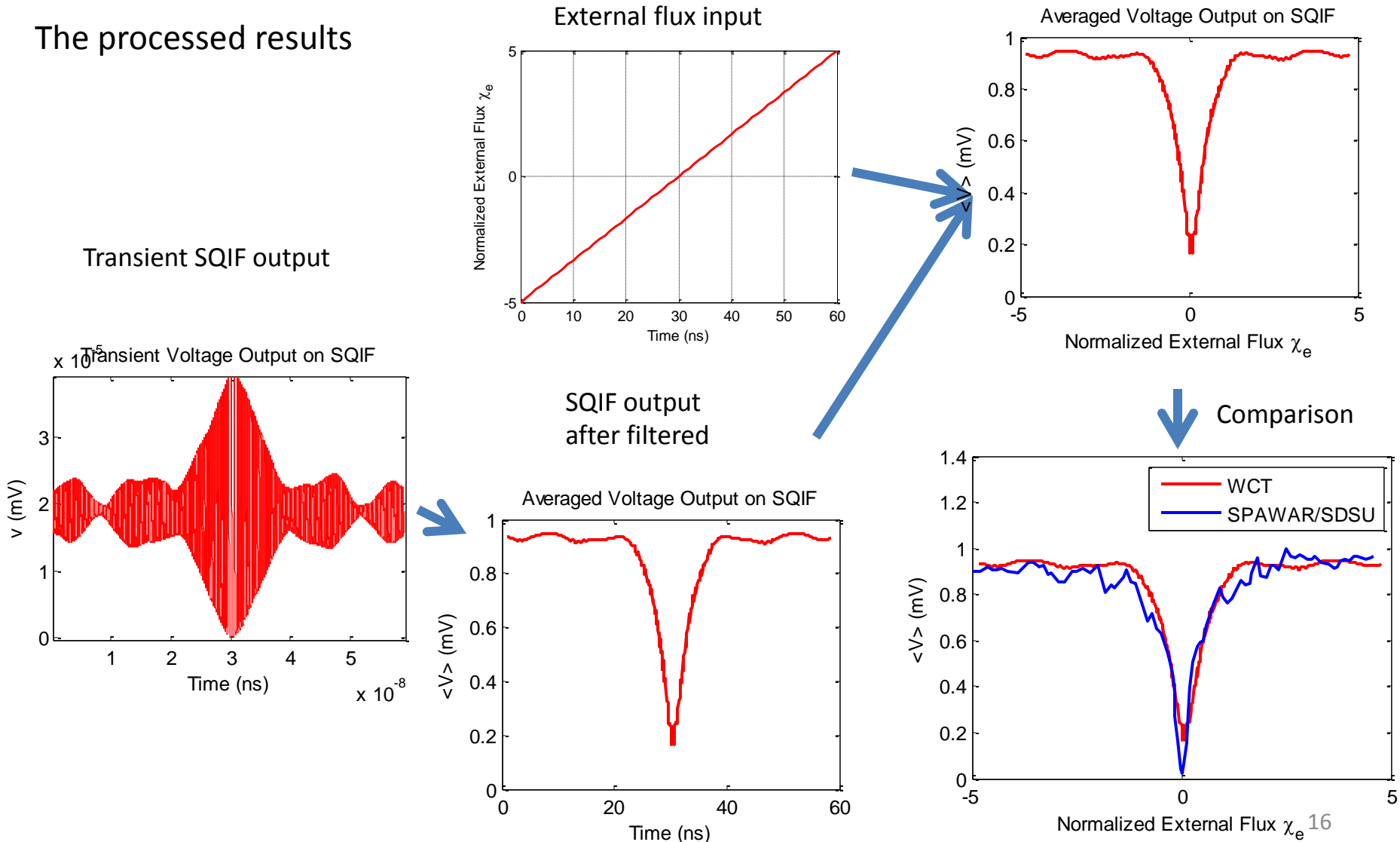
Same as case 1, right click mouse to export this voltage data as "a_40.txt"

Use matlab code to filter this data to obtain the dc voltage response of SQIF.

The matlab code is under the WCT project folder as:

[SQIF\demo\1D SQIF\serial\dc_voltage_response\40-loop-gaussian-p\ show_res_2.m](#)

The processed results

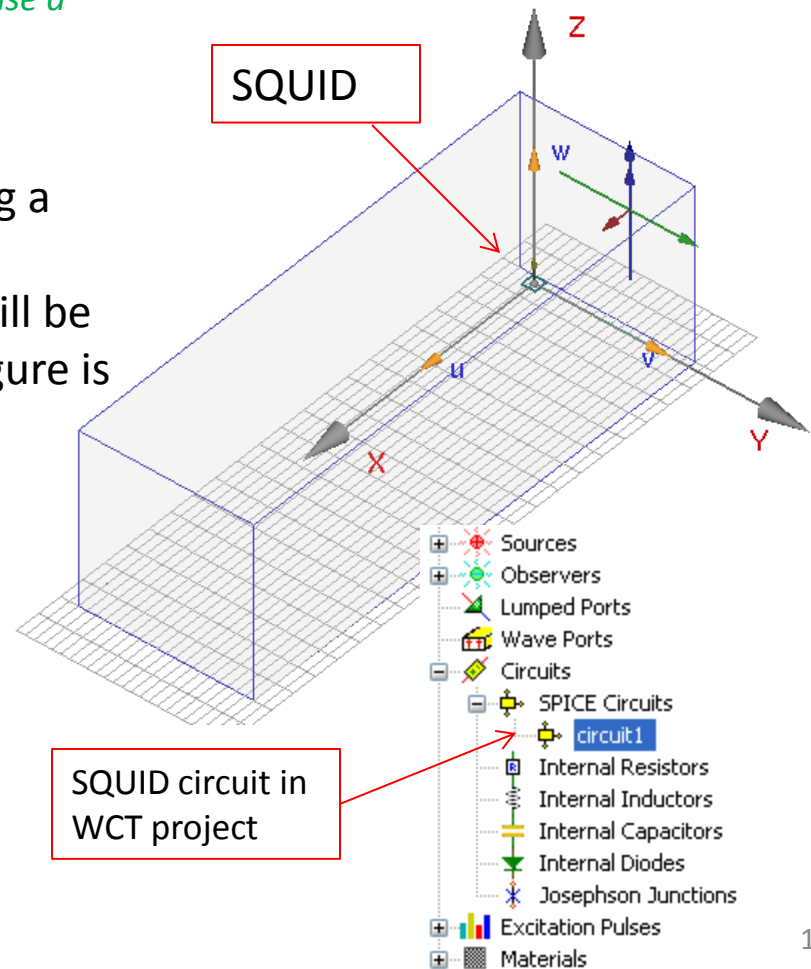
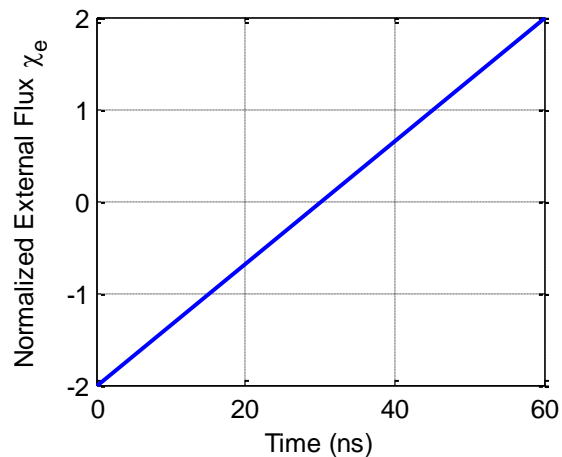


Case 3: Single loop dc SQUID with user input magnetic flux

- Case file: SQIF\demo\1D SQIF\single loop\dc_voltage_response\s1_2.wnt
- This case is used to show how to obtain **the dc voltage response** on a single loops dc SQUID

Due to a DC SQUID is a single loop SQIF. In this case, we use a single loop serial SQIF to represent a dc SQUID.

Similar to case 1 & 2, this case looks like using a plane wave incident. However, we define a external H field data file for SQIF. This data will be the actual H field input for SQIF. Following figure is the equivalent flux on a loop with $200 \mu\text{m}^2$.



Full SQIF circuit Setting

(note: This case we use TEXT format circuit. However, WCT also support graphic format circuit, it can be also used to build a SQIF circuit)

General

Name:

Circuit Text

```
sqif  
  
*bias current source  
ib 0 100 PwL(0 0 0.001e-9 0 0.002e-9 0.202e-3 1.0e-3 0.202e-3)  
x01 100 0 sqif1  
  
.tran 2p 60ns 0s 2p uic  
.end
```

Existing Subcircuits in Project

type	name	parameter
1D SQIF	sqif1	Loops=1

Ports

	Node Pair	Start Position	End Position
1	1, 0	0, 0, 0	1, 0, 0
2			
3			
4			

System Intrinsic Subcircuits

1D Sqif 2D Sqif DC-Squid

Buttons: Delete, Insert, Help, OK, Cancel

Parallel SQIF parameters

1D SQIF Editor

Name: Layout:

Loops Information

Loops No.: Loops Area Distribution Type:

Formula: $S=50+K*t$ (m^2)

Parameters: K

t range:

Parameters for each loop

Loop Center:

Loop Normal: Identical

Josephson Junctions: Identical

Self-inductance (H): Proportional to area Factor:

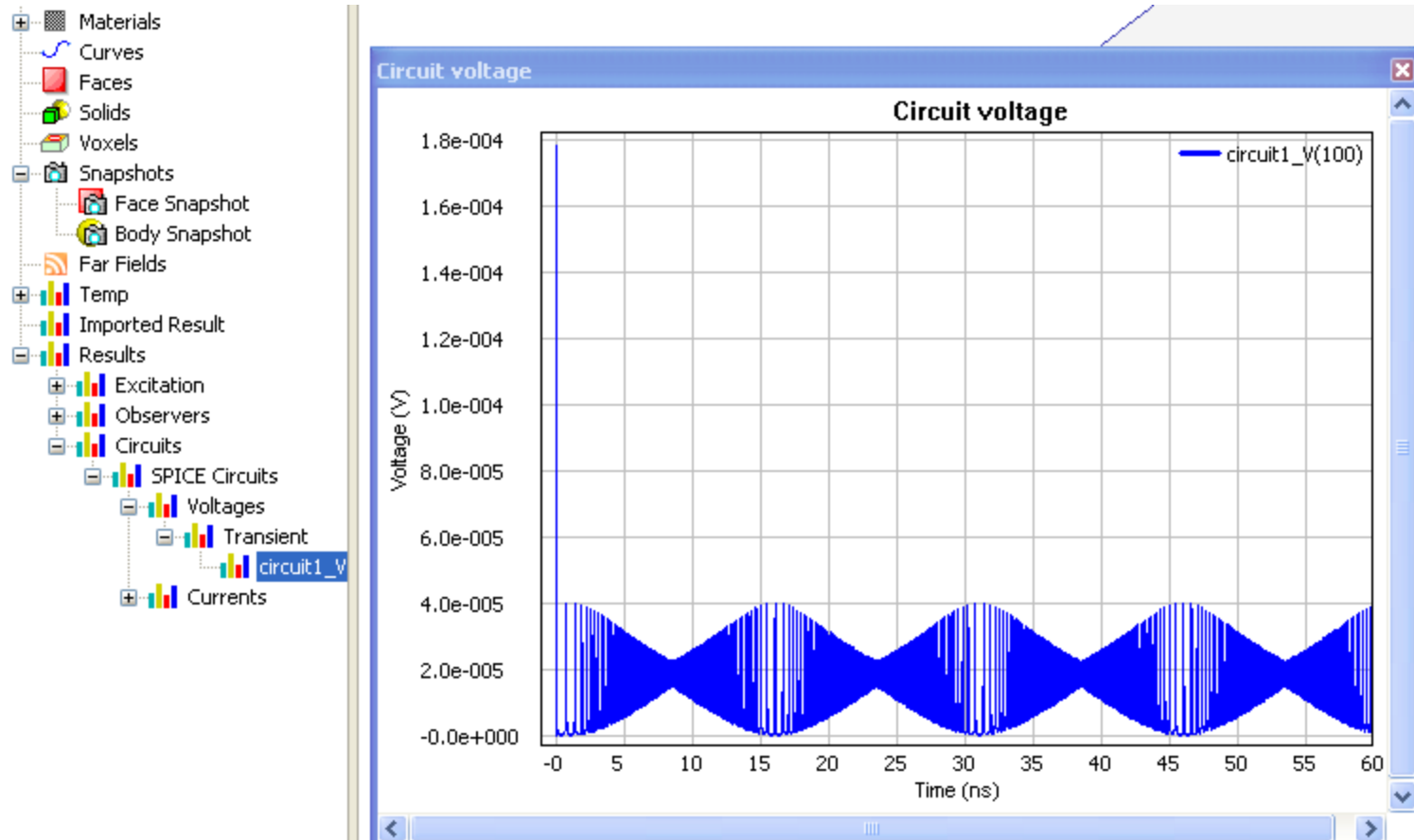
Mutual-inductance (H): Unit:

Bias DC current (A): Magn. Flux Density (B): Type:

Miscellaneous

DC Bias H Field (A/m): Startup Delay (s):

Transient output voltage of SQIF



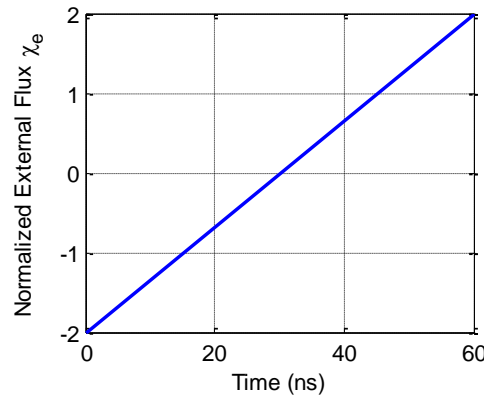
Same as case 1, right click mouse to export this voltage data as “a_1.txt”

Use matlab code to filter this data to obtain the dc voltage response of SQIF.
The matlab code is under the WCT project folder as:

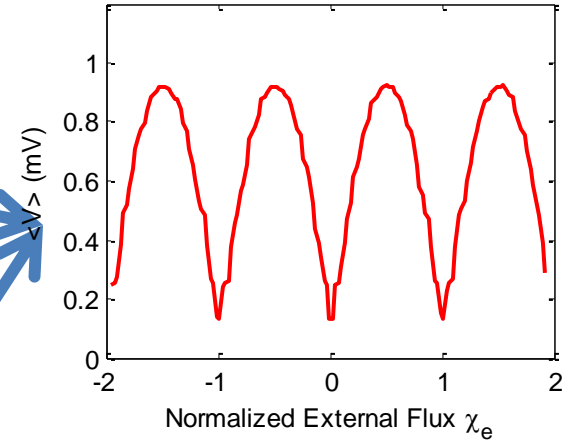
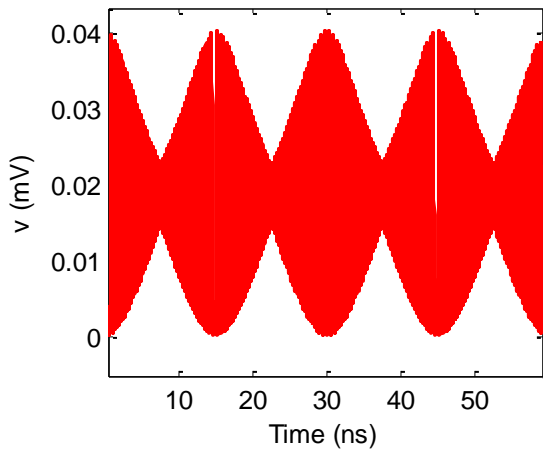
[SQIF\demo\1D SQIF\single loop\dc_voltage_response\show_res_2.m](#)

The processed results

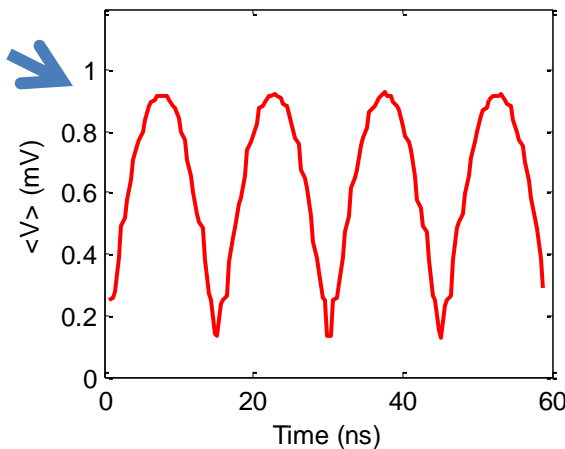
External flux input



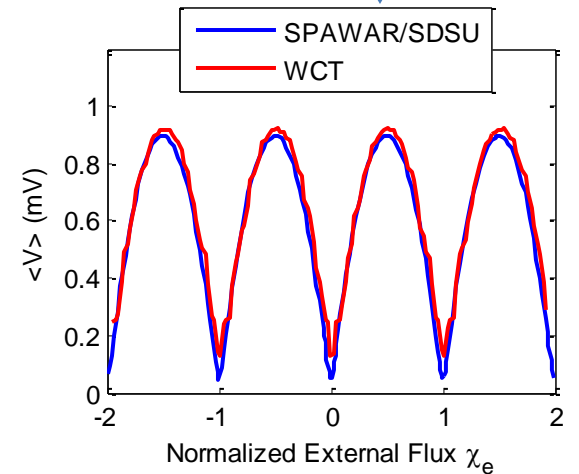
Transient SQIF output



SQIF output after filtered

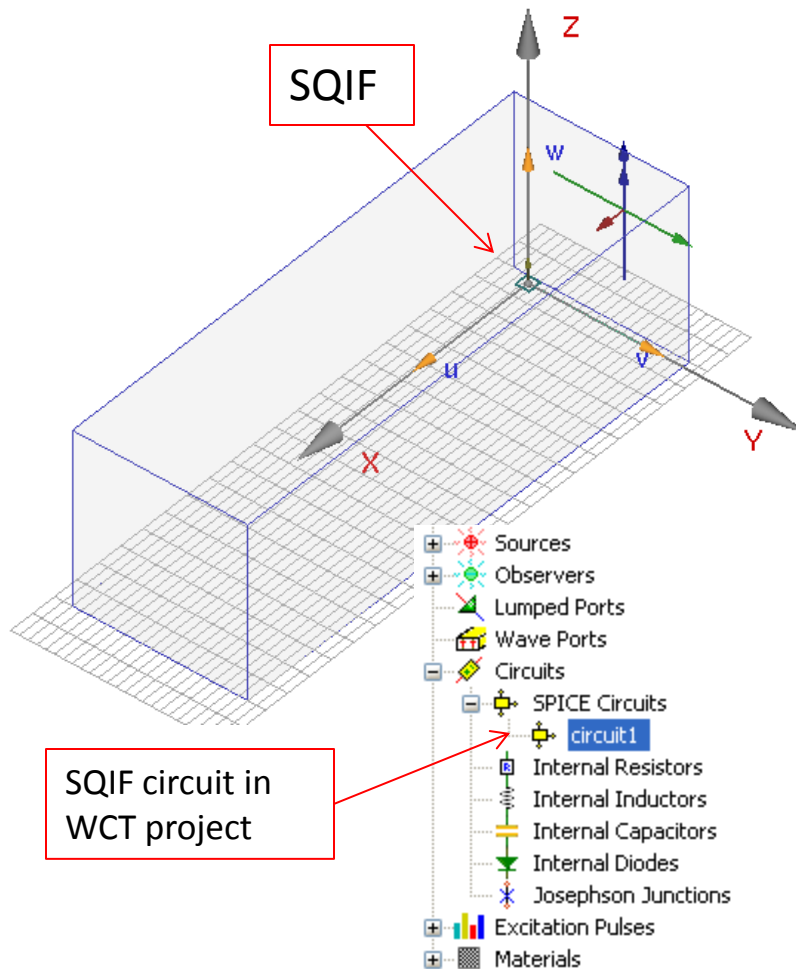


Comparison



Case 4: 1D Serial SQIF with plane wave incident

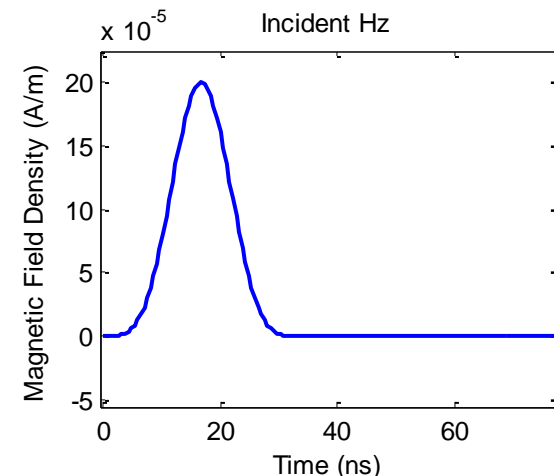
- Case file: SQIF\demo\1D SQIF\serial\plane_wave_incident\10_loops\case2_10loop.wnt
- This case is used to show how to use a 10 loops 1D serial dc SQIF to receive a incoming plane wave



This case use a plane wave incident. The SQIF device will convert received transient H field and export a transient voltage.

After filtered by a low-pass filter, the incoming wave can be re-constructed correctly.

Incoming plane wave



Full SQIF circuit Setting

(note: This case we use TEXT format circuit. However, WCT also support graphic format circuit, it can be also used to build a SQIF circuit)

General
Name:

Circuit Text

```
sqif  
*bias current source  
ib 0 100 PWL(0 0 0.001e-9 0 0.002e-9 0.22e-3 1.0e-3 0.22e-3)  
x01 100 0 sqif1  
  
.tran 1p 80ns 0s 1p uic  
.end
```

Existing Subcircuits in Project

type	name	parameter
1D SQIF	sqif1	Loops=10

Ports

	Node Pair	Start Position	End Position
1	1, 0	0, 0, 0	1, 0, 0
2			
3			
4			

System Intrinsic Subcircuits

1D Sqif 2D Sqif DC-Squid

Buttons: Delete, Insert, Help, OK, Cancel

SQIF parameters

1D SQIF Editor

Name: Layout:

Loops Information

Loops No.: Loops Area Distribution Type: *Linear loops area*

Formula: $S=S_0+K*t$ (m^2)

Parameters: S_0 K

t range: t_0 t_1

Parameters for each loop

Loop Center: *Loop centers*

Loop Normal: Identical

Josephson Junctions: Identical *Josephson Junction parameters*

Self-inductance (H): Proportional to area Factor:

Mutual-inductance (H): Unit:

Bias DC current (A): Magn. Flux Density (B): Type:

Miscellaneous

DC Bias H Field (A/m): Startup Delay (s):

3D Points Editor

(x, y, z)

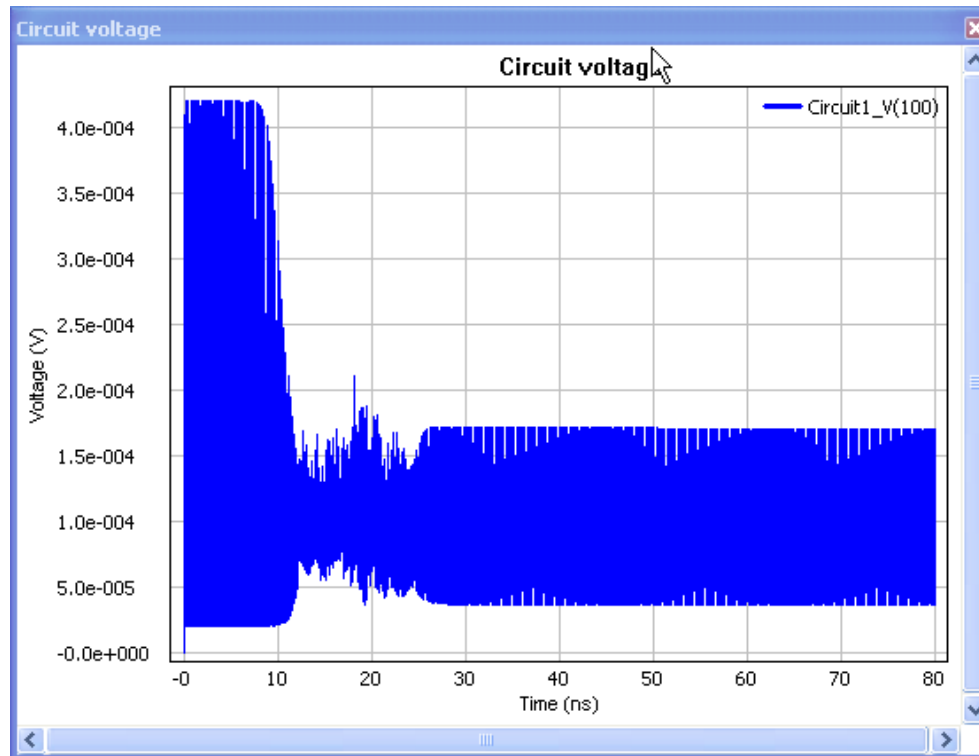
1	0.03, 0, 0
2	0.0314643, 0, 0
3	0.0328634, 0, 0
4	0.0342053, 0, 0
5	0.0354965, 0, 0
6	0.0367423, 0, 0
7	0.0379473, 0, 0
8	0.0391152, 0, 0
9	0.0402492, 0, 0
10	0.0413521, 0, 0

Squids in Sqif

DC-Squids in the Sqif

	Junction 1	Junction 2
2	Ic=0.0001;R=0.2;C=0	Ic=0.0001;R=0.2;C=0
3	Ic=0.0001;R=0.2;C=0	Ic=0.0001;R=0.2;C=0
4	Ic=0.0001;R=0.2;C=0	Ic=0.0001;R=0.2;C=0
5	Ic=0.0001;R=0.2;C=0	Ic=0.0001;R=0.2;C=0
6	Ic=0.0001;R=0.2;C=0	Ic=0.0001;R=0.2;C=0
7	Ic=0.0001;R=0.2;C=0	Ic=0.0001;R=0.2;C=0
8	Ic=0.0001;R=0.2;C=0	Ic=0.0001;R=0.2;C=0
9	Ic=0.0001;R=0.2;C=0	Ic=0.0001;R=0.2;C=0
10	Ic=0.0001;R=0.2;C=0	Ic=0.0001;R=0.2;C=0

Transient output voltage of SQIF



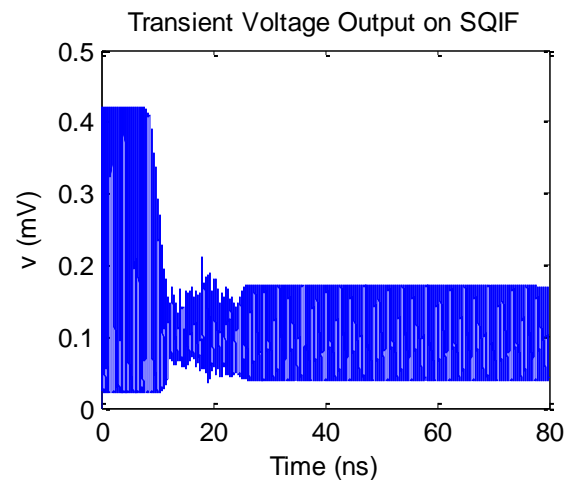
Same as case 1, right click mouse to export this voltage data as "v_out.txt"

Use matlab code to filter this data to reconstruct the received signal.

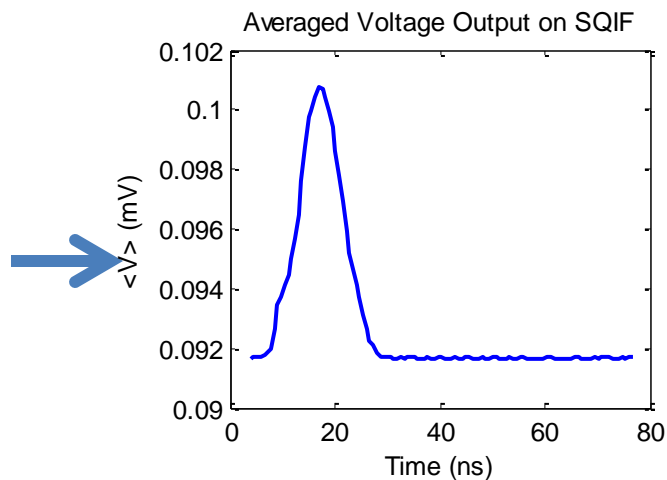
The matlab code is under the WCT project folder as:

[SQIF\demo\1D SQIF\serial\plane_wave_incident\10_loops\show_res_2.m](#)

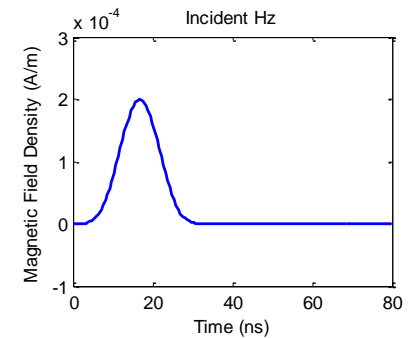
Transient SQIF output



SQIF output after filtered

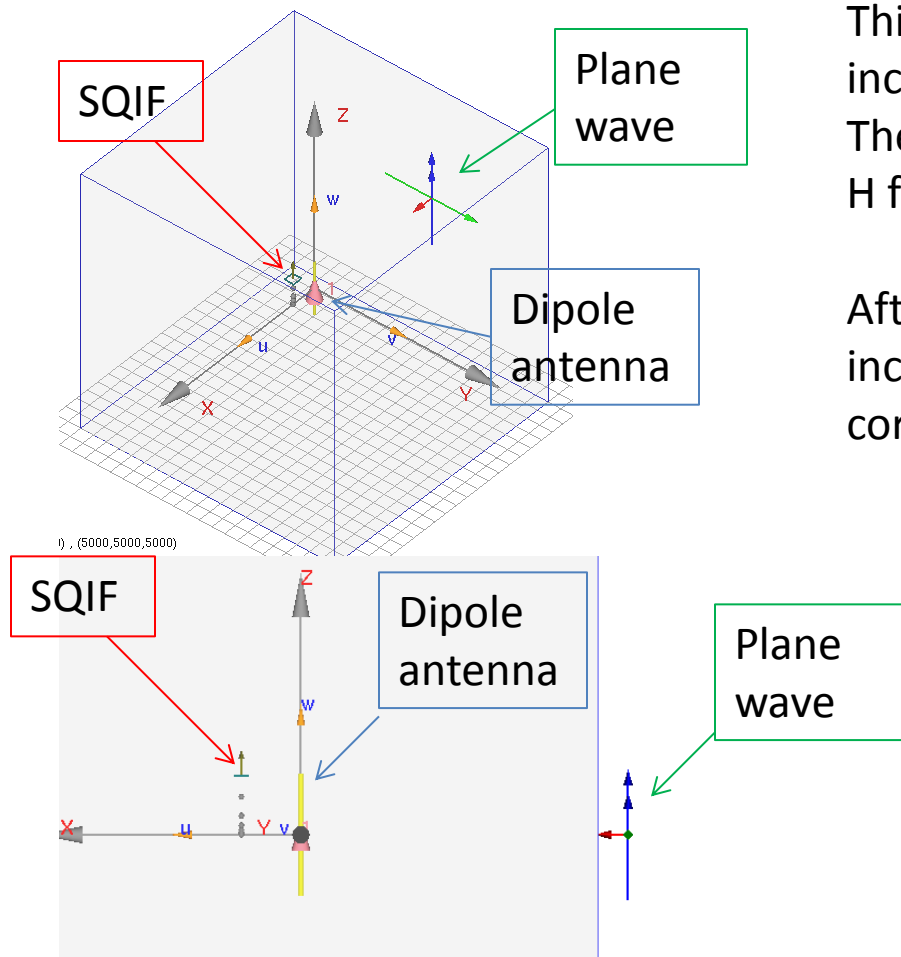


Incoming plane wave



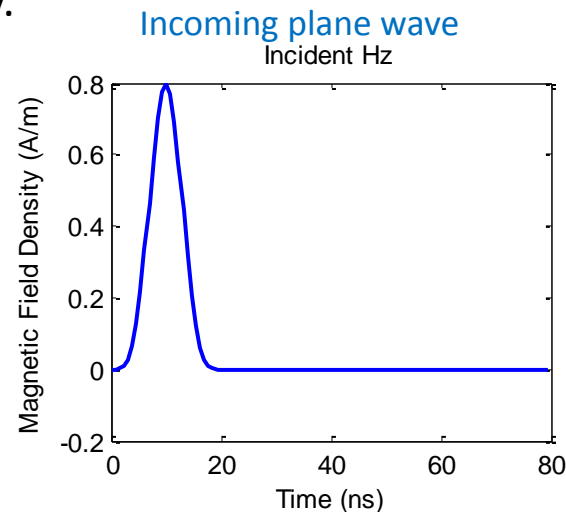
Case 5: 2D SQIF simulation with plane wave incident and dipole antenna

- Case file: SQIF\demo\2D SQIF\SQIF+PW+Dipole\system_sqif_10x10.wnt
- This case is used to show how to use a 10x10 loops 2D dc SQIF to pickup a incoming plane wave from the strong interference from nearby dipole antenna
- note:
 1. the simulation time for this case is about 3 minutes on x32 version
 2. the 2D SQIF array has not been verified with experimental data yet



This case has two signal source: an incident plane wave and a dipole antenna. The SQIF device will receive the transient H field from the plane wave only.

After filtered by a low-pass filter, the incoming wave can be re-constructed correctly.



Full SQIF circuit Setting

(note: This case we use TEXT format circuit. However, WCT also support graphic format circuit, it can be also used to build a SQIF circuit)

Modify Lumped Circuit

General
Name:

Circuit Text

```
sqif
*bias current source
ib 0 100 PWL(0,0,0,001e-9,0,0,002e-9, 11, 11e-4, 1, 0e-3, 11, 11e-4)
x01 100 0 sqif2
.tran 2p 80ns 0s 2p uic
.end
```

dc bias current

SQIF

Existing Subcircuits in Project

type	name	parameter
2D Rec...	sqif2	11x11 array

Delete

System Intrinsic Subcircuits

1D Sqif 2D Sqif DC-Squid

Insert

Help OK Cancel

SQIF parameters

2D Rectangular SQIF Array

Name

Grid Position in XOY Plane

X (Unit: m)

1	1
2	1.00001
3	1.00002
4	1.00003
5	1.00004
6	1.00005
7	1.00006
8	1.00007
9	1.00008
10	1.00009
11	1.0001
12	

Y (Unit: m) [JJ branch]

1	1e-005
2	3e-005
3	5e-005
4	7e-005
5	9e-005
6	0.00011
7	0.00013
8	0.00015
9	0.00017
10	0.00019
11	0.00021
12	

Load

Sort

Clear

Load

Sort

Clear

Loops grid

Josephson Junctions on Y Edges

Identical Critical Current (A) Resistance (Ohm) Capacitance (F)

Function Distribution X Direction Y Direction

User Input

Additional Transform (Sequentially)

(1) Translation (Unit: m)

(2) Rotations (unit: degree) (2) SQIF Plane Normal (x,y,z)

Around X axis

Around Y axis

Around Z axis

(3) Translation (Unit: m)

Unit Length Inductance (H/m)

Including Mutual Coupling

Random JJ Variation

JJ Beta

Josephson Junction parameters

3D position translation of SQIF

Miscellaneous

DC Bias H Field (A/m)

Startup Delay (s)

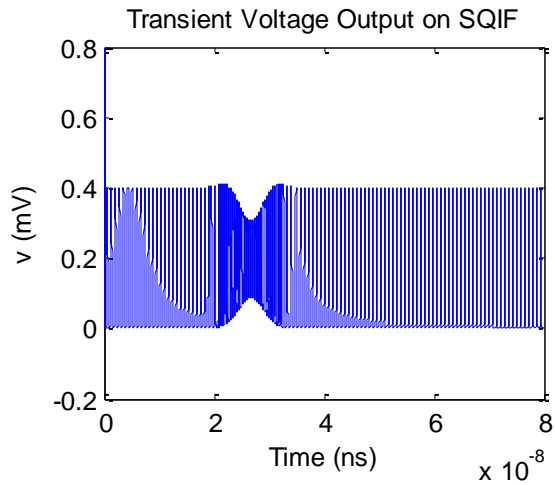
Help

OK

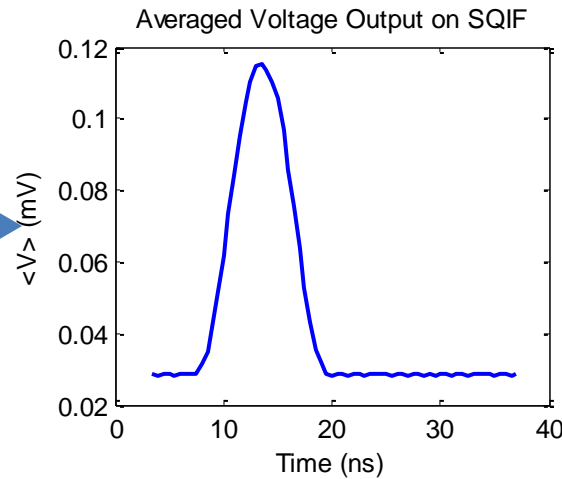
Cancel

Use matlab code to filter this data to reconstruct the received signal.
The matlab code is under the WCT project folder as:
[SQIF\demo\ 2D SQIF\SQIF+PW+Dipole \show_res_2.m](#)

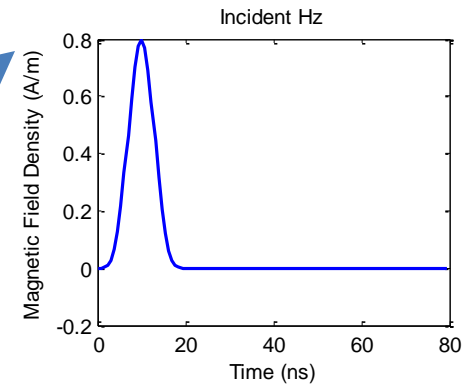
Transient SQIF output



SQIF output after filtered



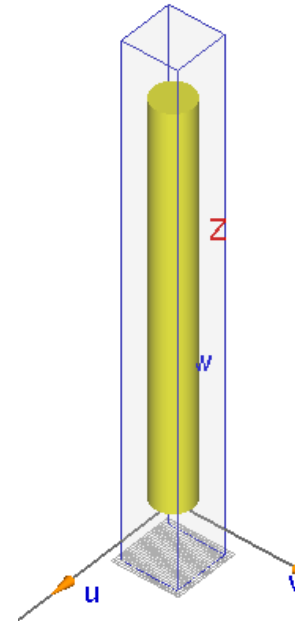
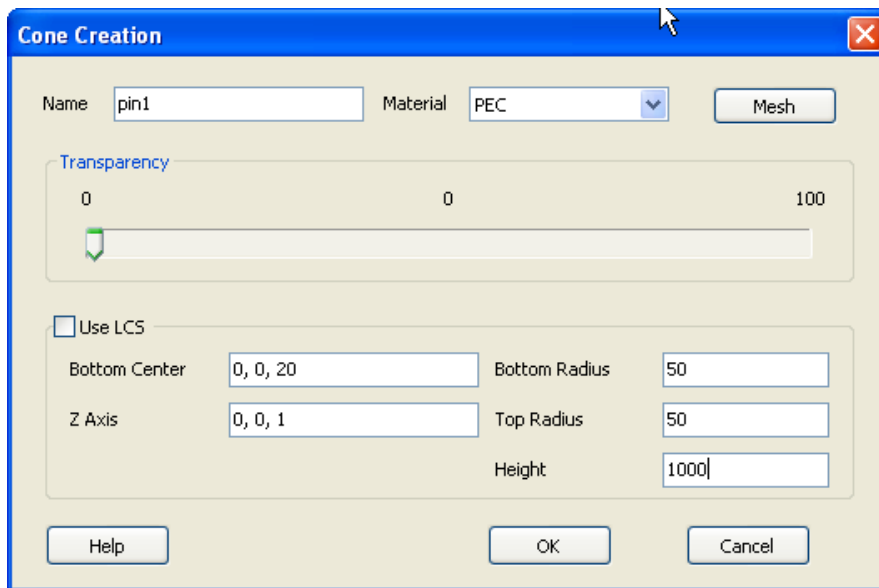
Incoming plane wave



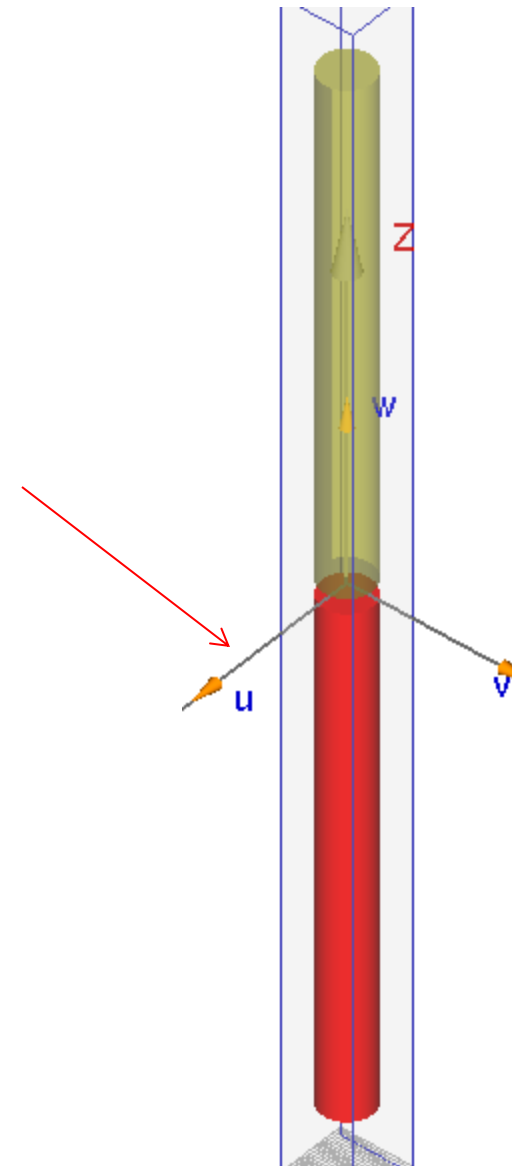
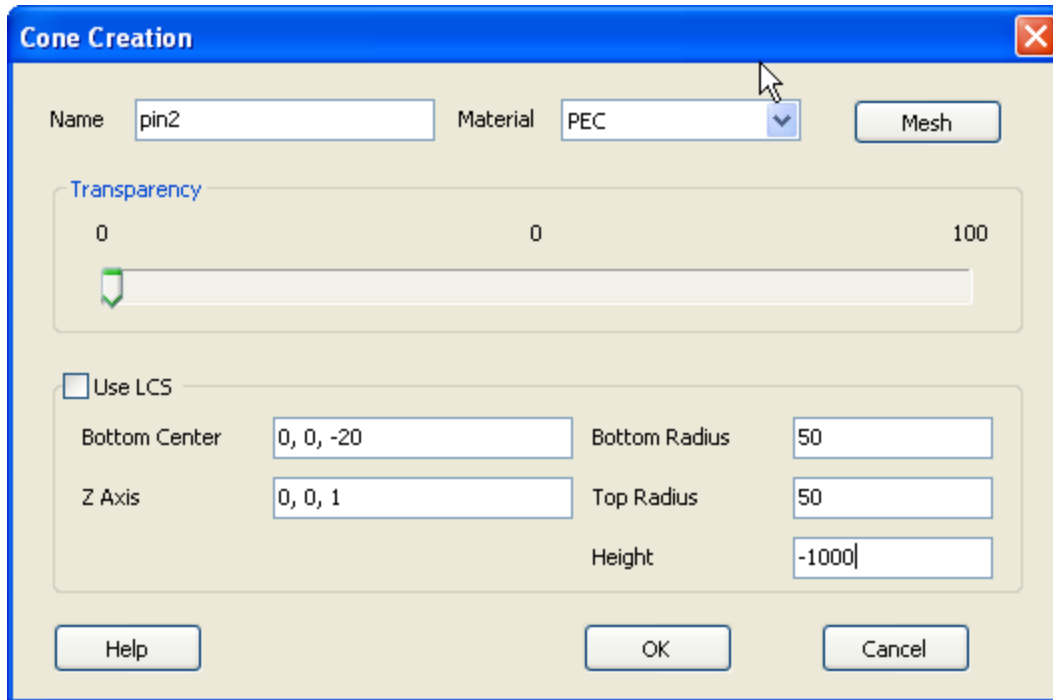
Set up a SQIF and EM Simulation using case 5

1. Start a default WCT EM case.
2. Build the dipole antenna

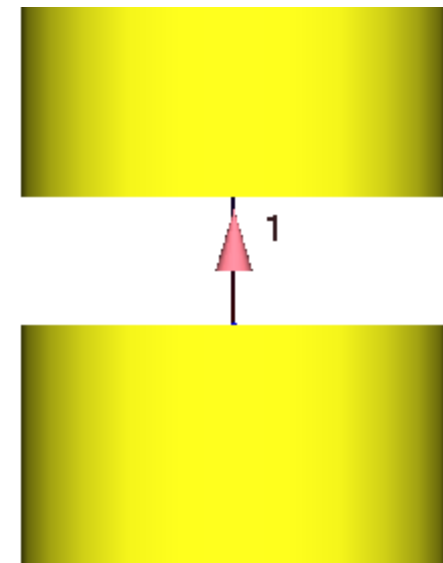
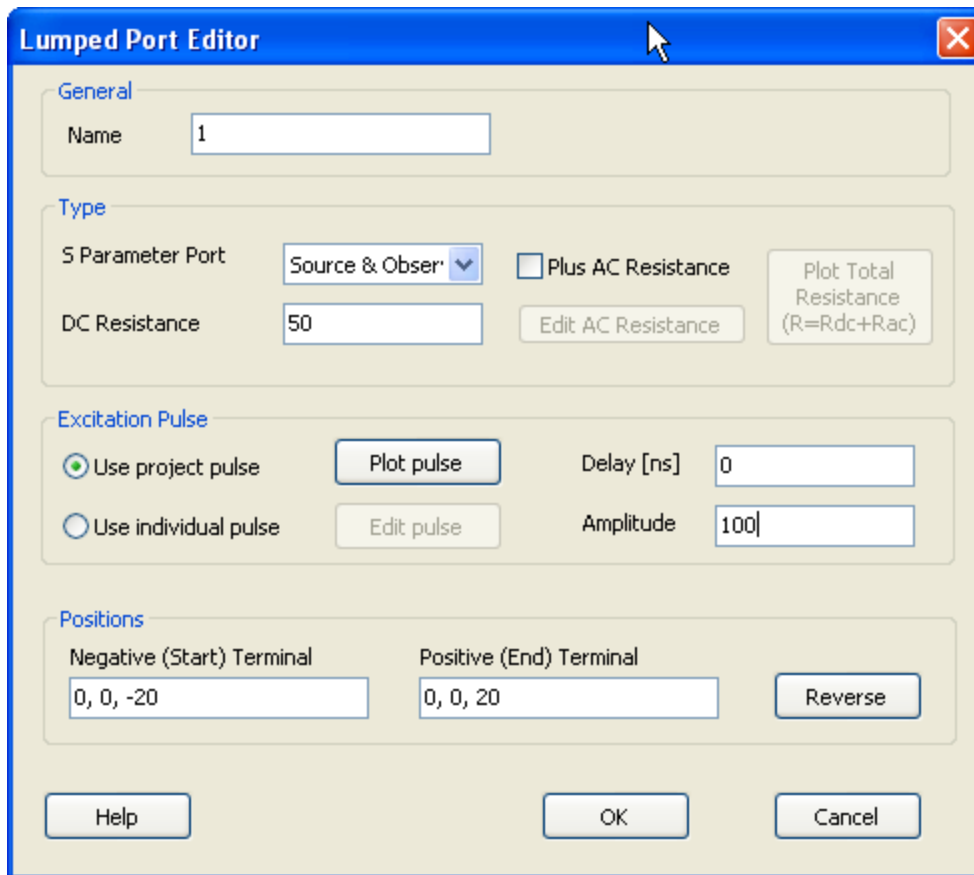
2.1 Top pin (use WCT **CONE** shape)

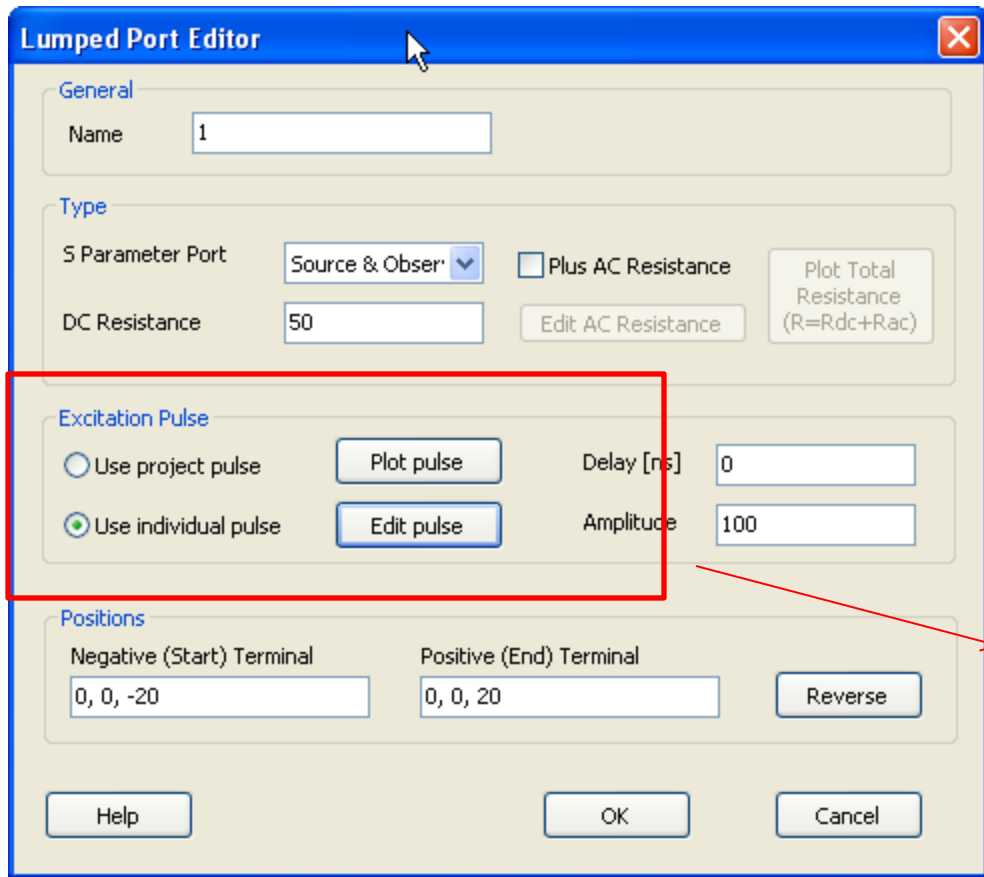


2.2 Bottom pin (use WCT **CONE** shape)



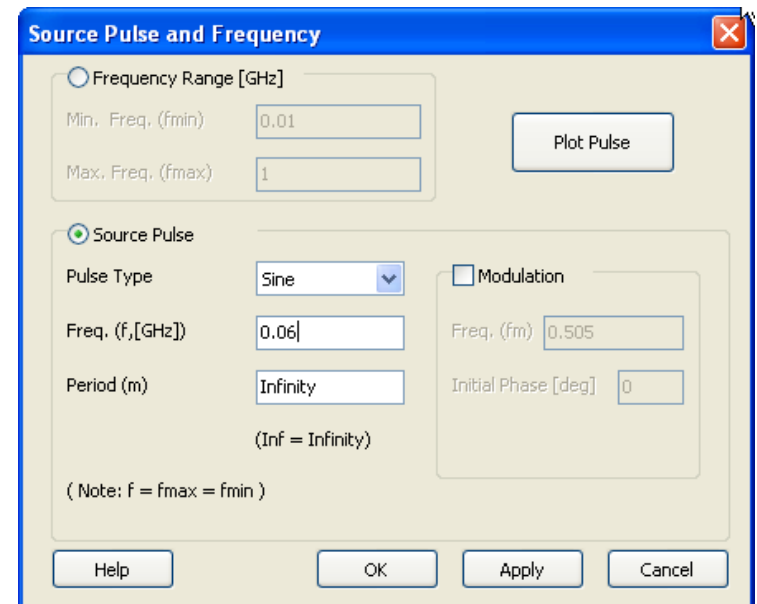
2.3 add a lumped port source which can excite the dipole antenna. This lumped port has an excitation voltage of 100 V.





We will let the dipole antenna sending single freq. signal.

So, we change the lumped port excitation waveform to a infinite sinusoid wave.



3. Add an incoming plane wave.

This plane is a **z** polarized H plane wave with a magnitude of 0.8 A/m.

This plane wave use project pulse.

Create New Source

Name: Type:

Prop. Dir.(deg) (theta, phi): Polarization:

Excitation Pulse

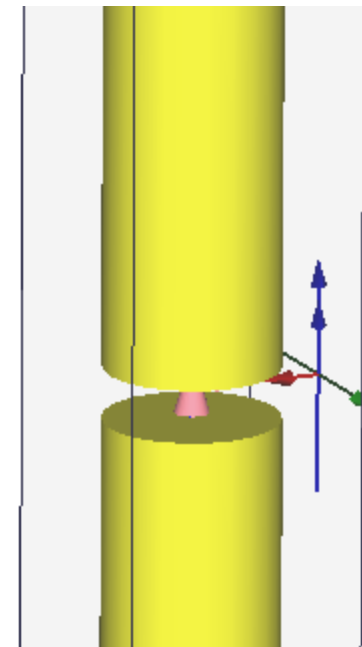
Use project pulse

Use individual pulse

Pulse type:

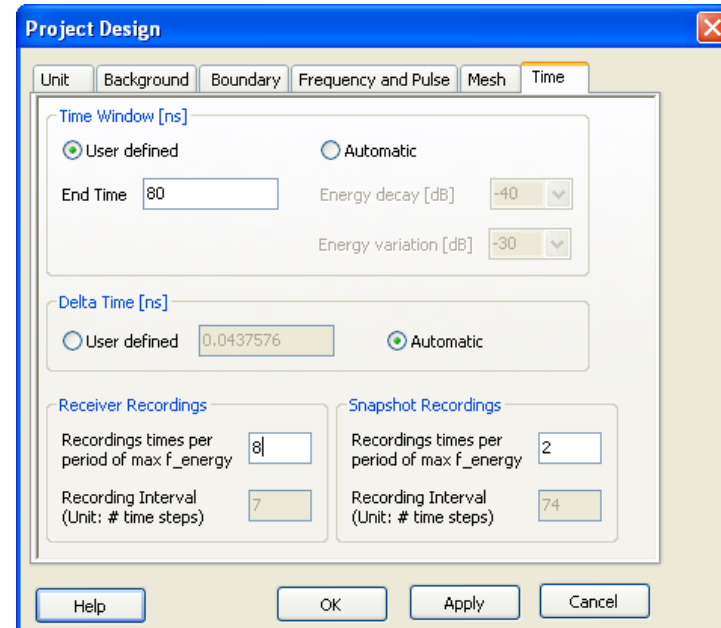
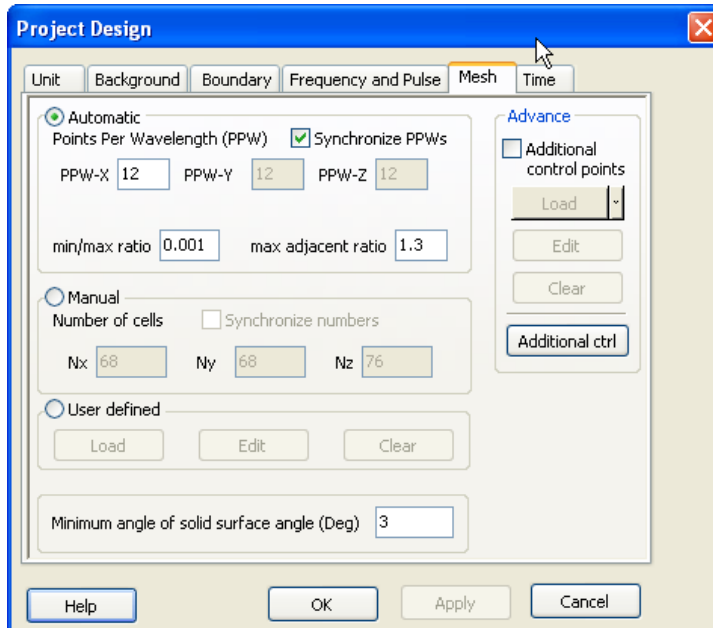
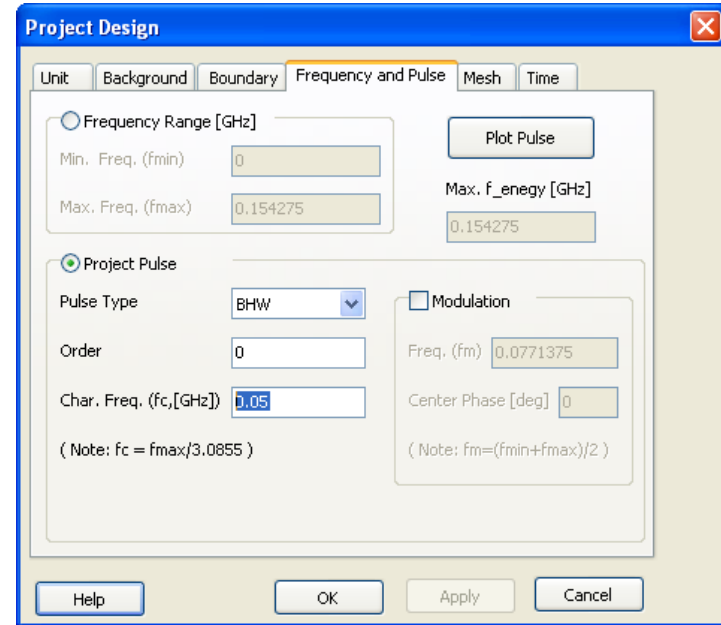
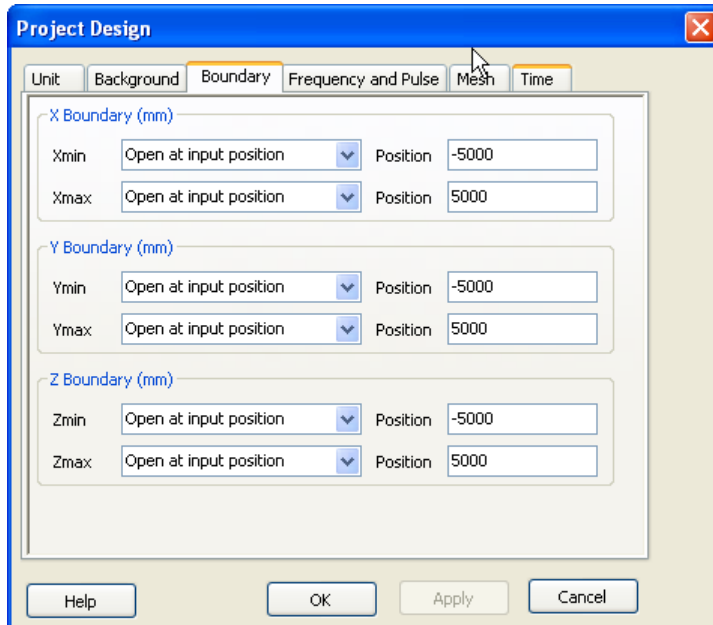
Delay [ns]:

Amplitude:



4. Change project setting.

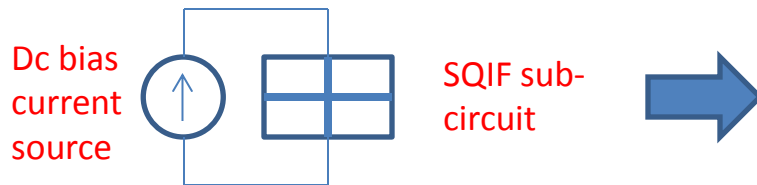
Include project size, meshing density and simulation time.



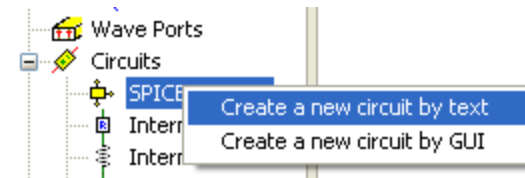
5. Setup 2D SQIF.

In this demo, we use TEXT format circuit. We will show how to use Graphic format circuit in the other cases.

A dc SQIF circuit has following structure.



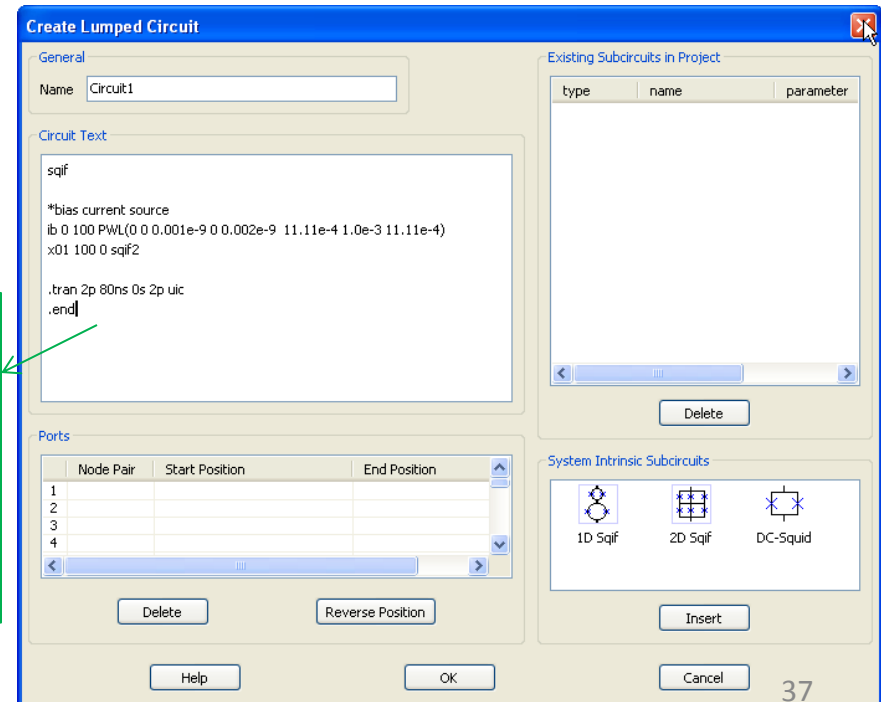
Write a basic SPICE circuit with left structure.



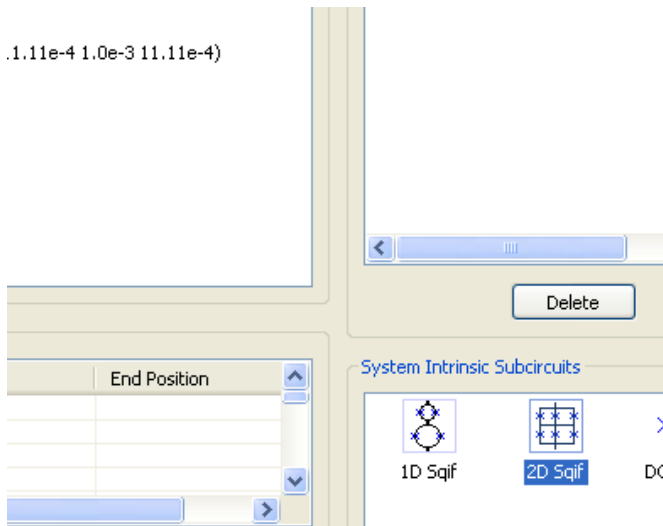
Because we use a 10x10 2D SQIF. It has 11 parallel Josephson Junctions. The I_c of Josephson Junction is 0.1 mA. Our setup use $1.01I_c$ for each Josephson Junction. So the total $I_b=1.111$ mA.

```
sqif
*bias current source
ib 0 100 PWL(0 0 0.001e-9 0 0.002e-9 11.11e-4 1.0e-3 11.11e-4)
x01 100 0 sqif2
.tran 2p 80ns 0s 2p uic
.end
```

Set SQIF solver simulation time window as EM simulation time window.



After the main circuit is built, we need to let the main circuit connect to SQIF.



Double click this 2D SQIF sub-circuit to popup a 2D SQIF editor.



2D Rectangular SQIF Array

Name:

Grid Position in XOY Plane

X (Unit: m)

1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	

Y (Unit: m) [JJ branch]

1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	

Load Sort Clear

Josephson Junctions on Y Edges

Identical Critical Current (A) Resistance (Ohm) Capacitance (F)

Function Distribution X Direction Y Direction

User Input

Additional Transform (Sequentially)

(1) Translation (Unit: m)

(2) Rotations (unit:degree) (2) SQIF Plane Normal (x,y,z)

Around X axis

Around Y axis

Around Z axis

(3) Translation (Unit: m)

Unit Length Inductance (H/m)

Including Mutual Coupling

Random JJ Variation

JJ Beta

Miscellaneous

DC Bias H Field (A/m) Startup Delay (s)

Setup 2D SQIF parameters

2D Rectangular SQIF Array

Name:

Grid Position in XOY Plane

X (Unit: m)

1	1
2	1.00001
3	1.00002
4	1.00003
5	1.00004
6	1.00005
7	1.00006
8	1.00007
9	1.00008
10	1.00009
11	1.0001
12	

Y (Unit: m) [JJ Branch]

1	1e-005
2	3e-005
3	5e-005
4	7e-005
5	9e-005
6	0.00011
7	0.00013
8	0.00015
9	0.00017
10	0.00019
11	0.00021
12	

Josephson Junctions on Y Edges

Identical Critical Current (A) Resistance (Ohm) Capacitance (F)

Function Distribution X Direction Y Direction

User Input

Additional Transform (Sequentially)

(1) Translation (Unit: m)

(2) Rotations (unit:degree) (2) SQIF Plane Normal (x,y,z)

Around X axis

Around Y axis

Around Z axis

(3) Translation (Unit: m)

Unit Length Inductance (H/m)

Including Mutual Coupling

Random JJ Variation

JJ Beta

Miscellaneous

DC Bias H Field (A/m) Startup Delay (s)

Note: make sure the 2D SQIF sub-circuit name is the same as the one used in main circuit.

sqif

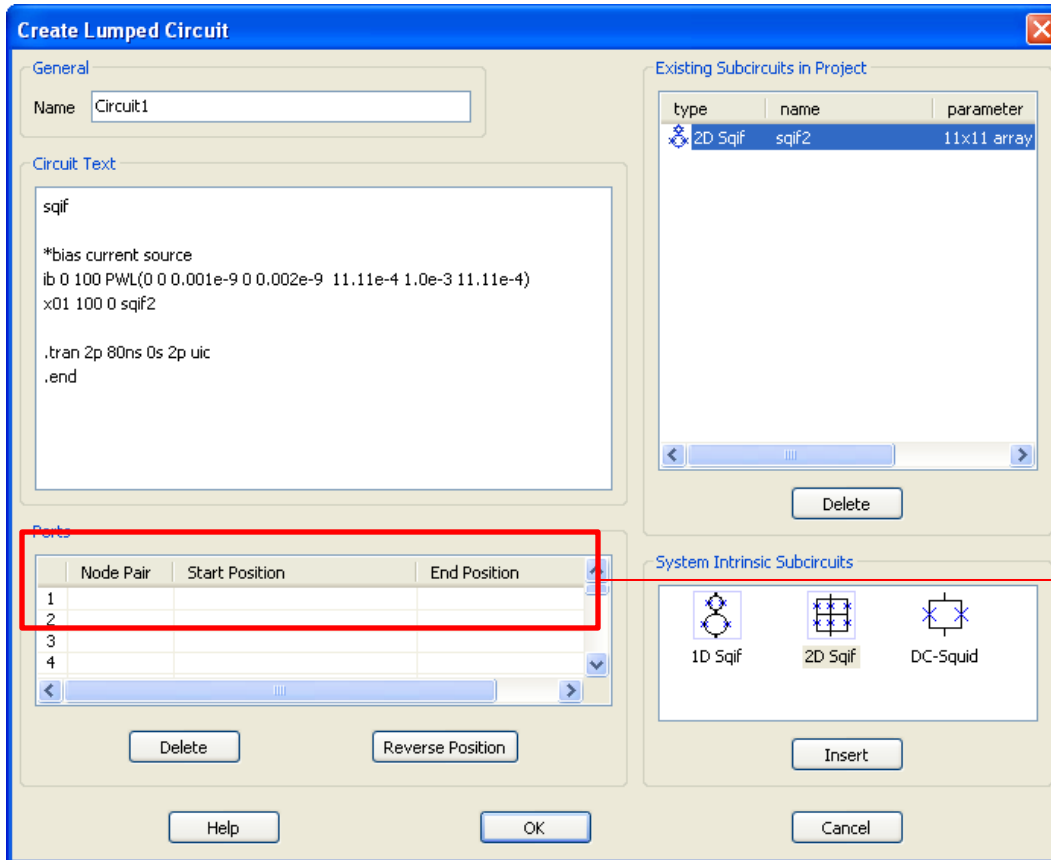
*bias current source

```
ib 0 100 PWL(0 0 0.001e-9 0 0.002e-9 11.11e-4 1.0e-3 11.11e-4)
x01 100 0 sqif2
```

```
.tran 2p 80ns 0s 2p uic
```

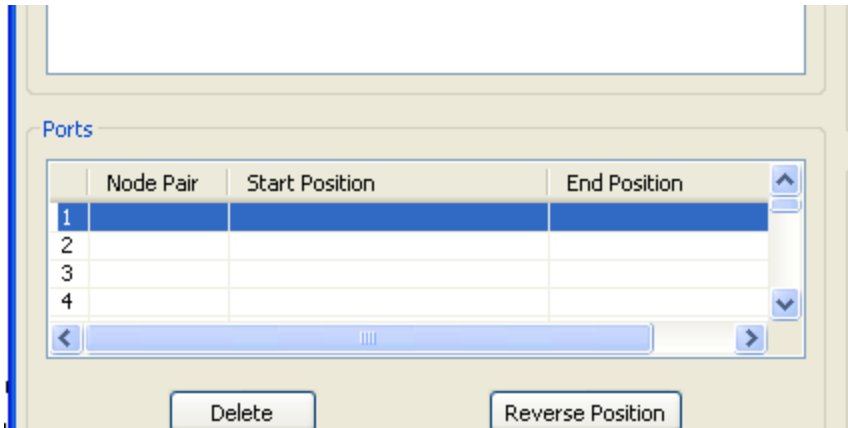
```
.end
```

After SQIF parameter is done.

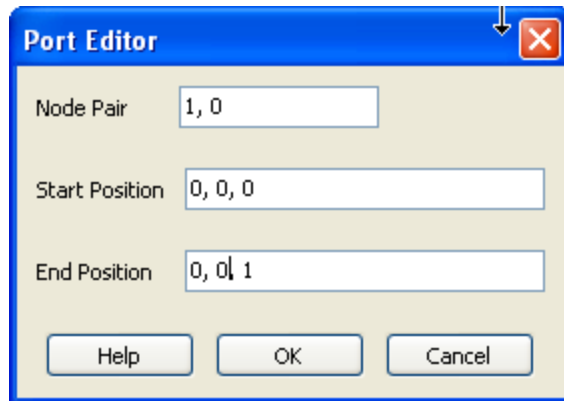


Need to add some other input to let this circuit can be fully support by WCT circuit solver.

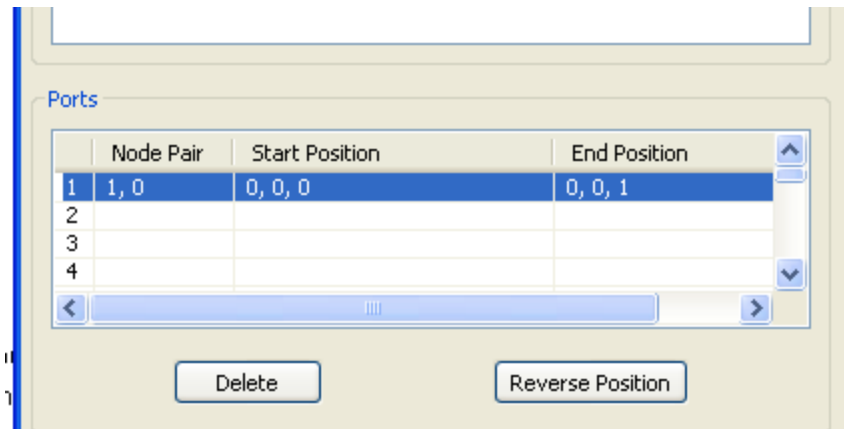
Actually, for a SQIF simulation, we don't need this information in SQIF solver. However, in current WCT version, user need to add this information to make circuit definition compatible with whole system.



Double click this item



Type in this information



5. Simulate to get result.

