FIRST-PASS SYSTEM SUCCESS

APPLICATION WORKSHOPS FOR HIGH-PERFORMANCE ELECTRONIC DESIGN

System Optimization of Motor Resolver including Drive Circuitry and Cable Parasitics

Ansoft Corporation

Abstract

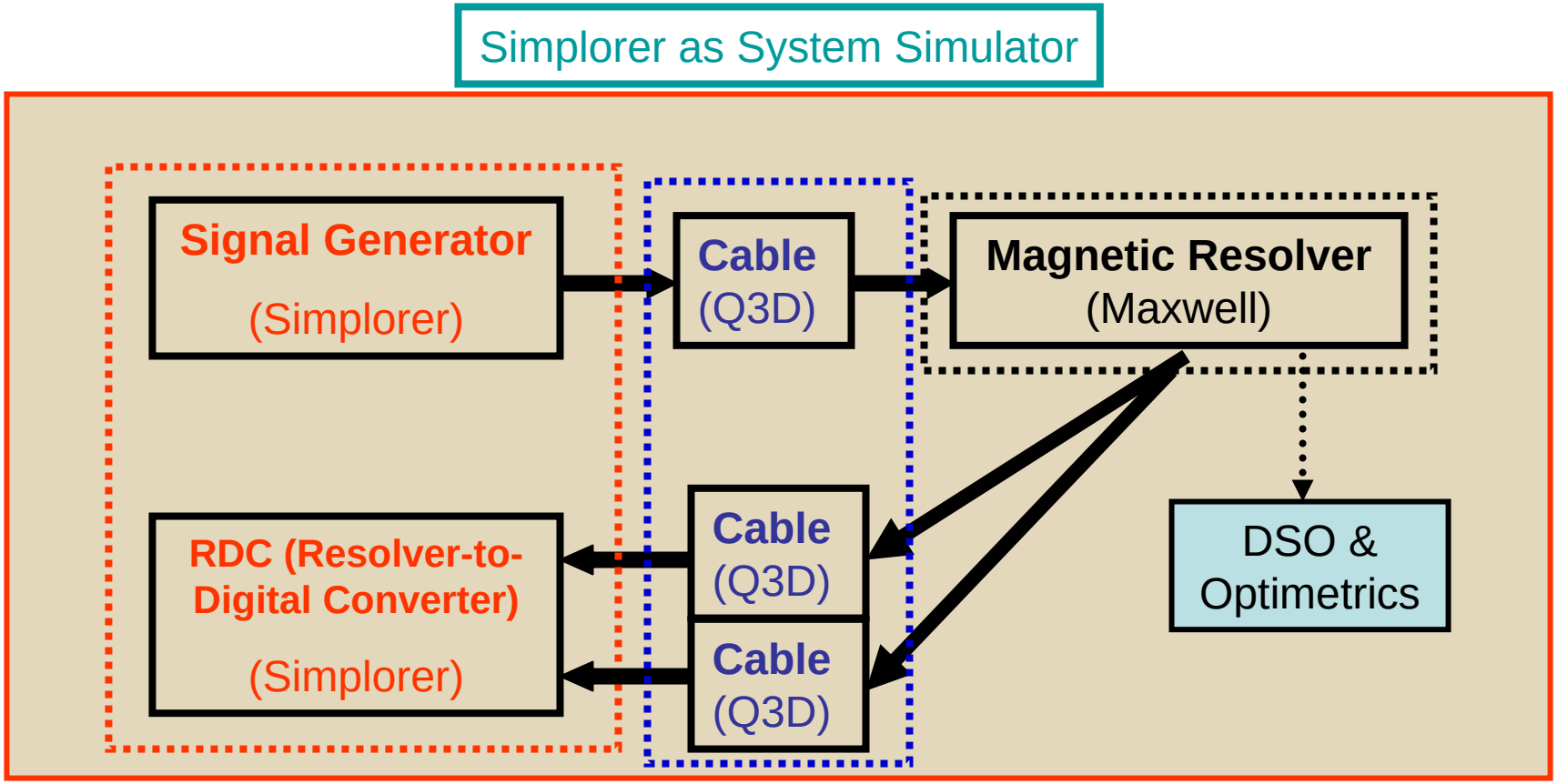
- Resolver as an angular position sensor is widely used
- Resolver system is complicated, equation based method is insufficient
- Resolver normally operates in the environment that has EMI/EMC issue
- Fast response and accurate position feedback is critical in the electrification of automotives and aircrafts
- A system level circuit simulator is needed to accurately account for all the above-mentioned factors

Outline

- Variable Reluctance Resolver FEA Model
- Resolver Excitation Signal Generator
- Resolver-to-Digital Converter
- Ideal Resolver System Behavioral Model
- Resolver Cable Parasitics
- Resolver System Integration
- Conclusions

Resolver System Simulation

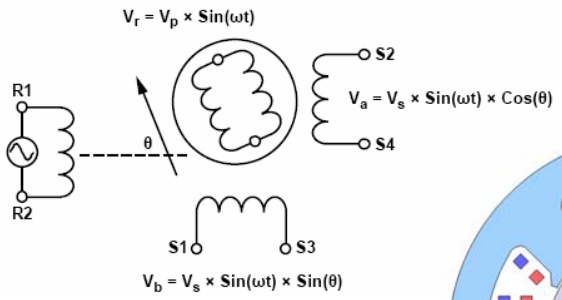
Simplorer, Q3D, Maxwell, DSO, Optimetrics

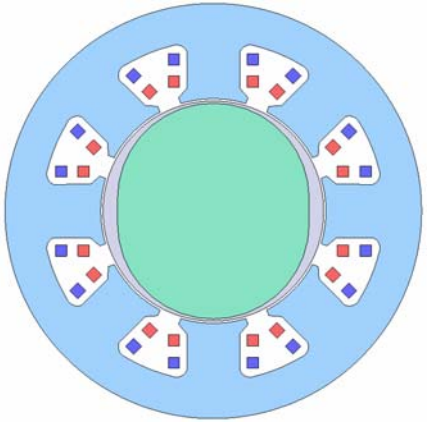


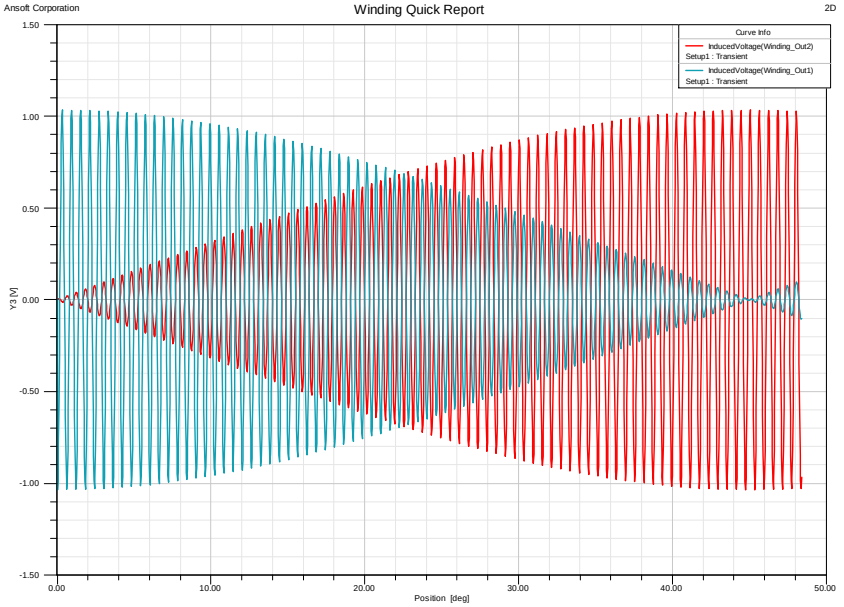
Advantages of Resolver over Optical Encoder

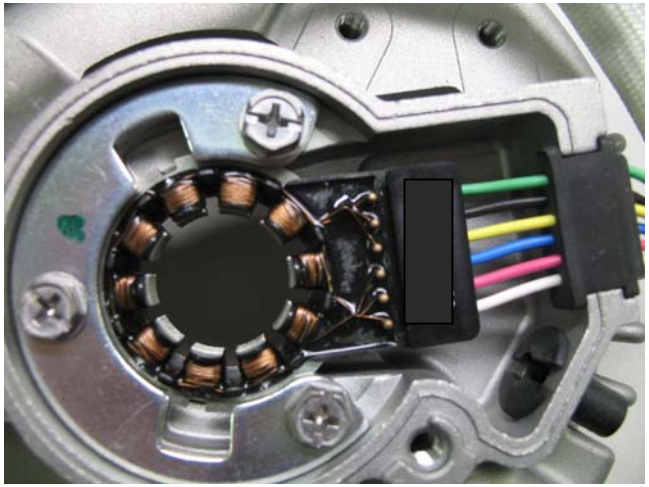
- Higher Resolution (up to 16-bit)
- Wider Environment Temperature (-55~+220ºC max)
- Higher Tolerance to Vibration (20~40g's)
- Higher Tolerance to Dust
- Robust EMC/EMI Performance(no electronics on board, cab be shielded)
- More Sizes Available

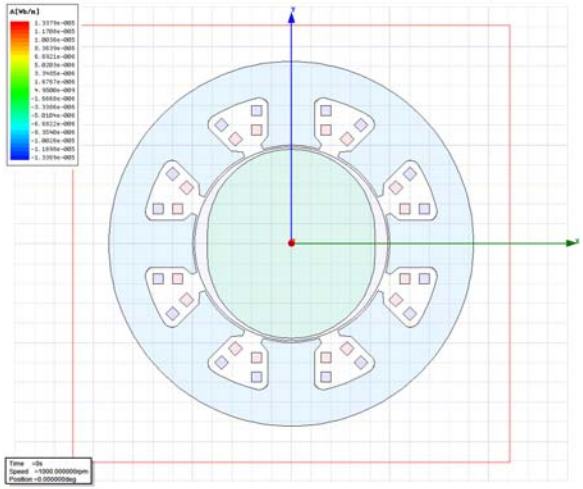
Resolver FEA Model





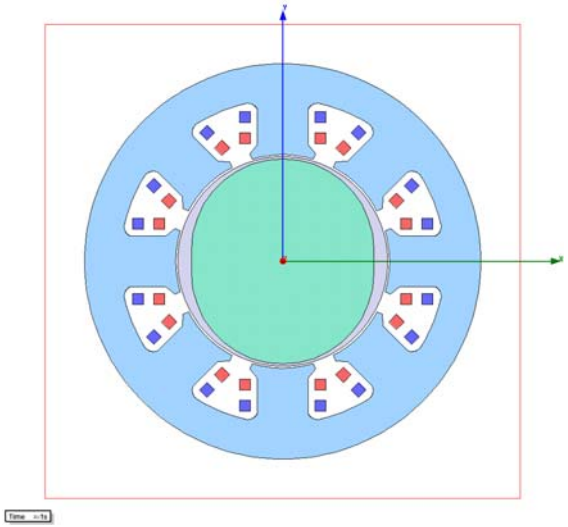


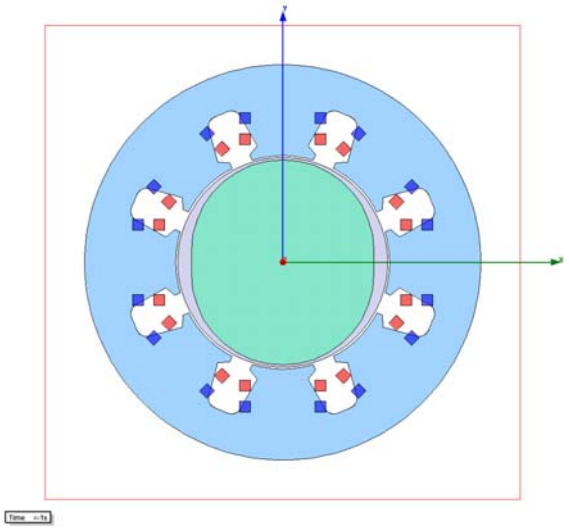


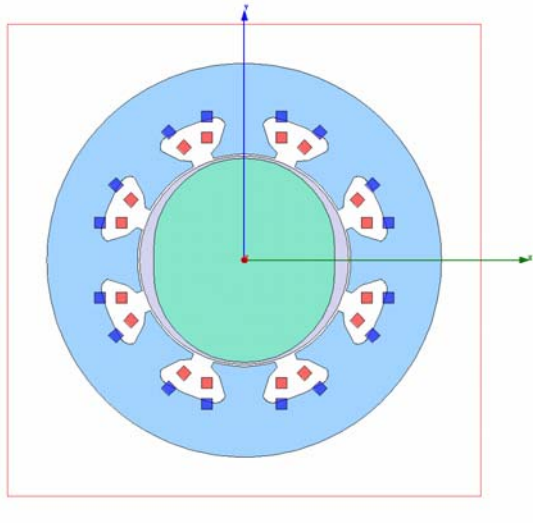


FIRST-PASS SYSTEM SUCCESS
APPLICATION WORKSHOPS FOR HIGH-PERFORMANCE ELECTRONIC DESIGN

Resolver Design Optimization



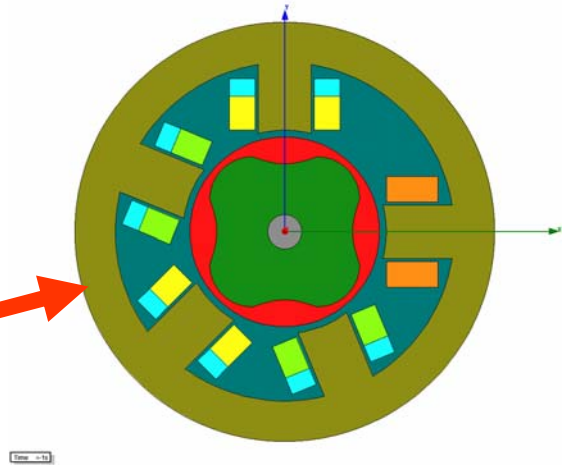




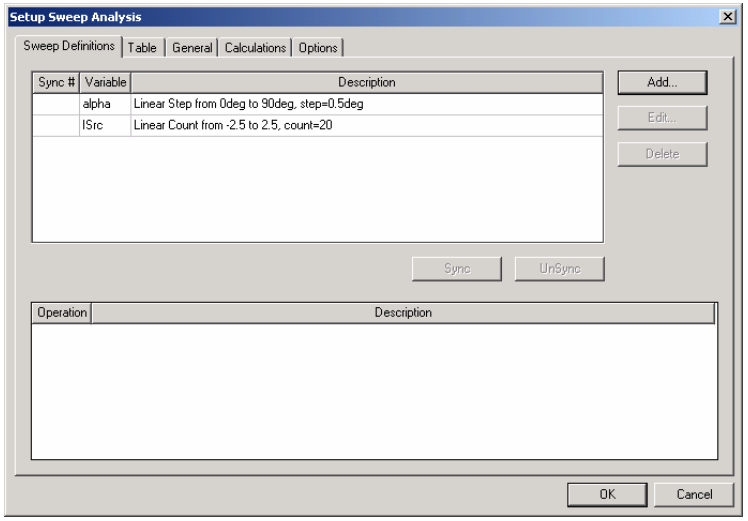
-Parametric Sweep Geometry
-Sweep Number of Turns in the Slots
-Check Different Winding Arrangements
-Try Different Materials
-Innovate New Designs
-Etc.

Goal:

* Optimize Outputs
* Reduce Cost

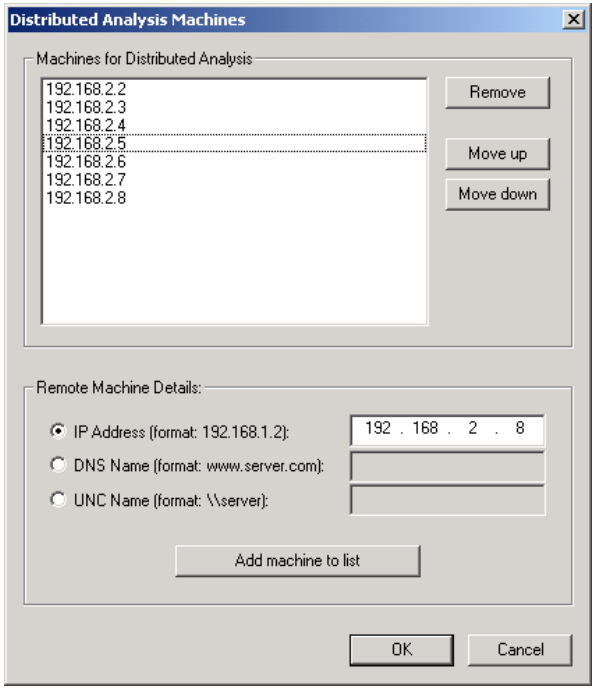


Creating an Equivalent Circuit Model for the Resolver



Sweep Angle (0~90 deg, in steps of 0.5 deg)
Sweep Source Magnitude (-2.5~2.5 Amp Turns, 20 counts)
Total: 181*20 = 3,620 rows
Each row takes 50 seconds to simulate
Total simulation time on one machine = 181,000 seconds

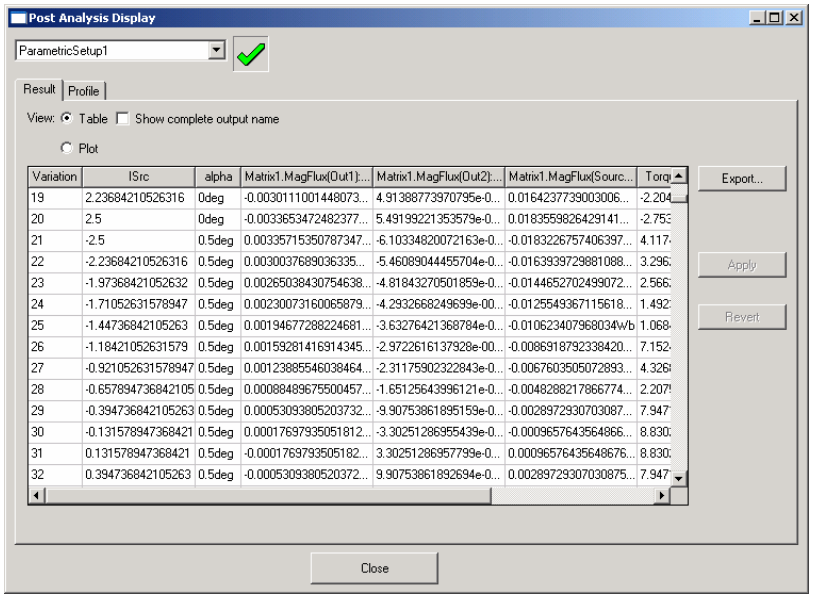
50.28 Hours!



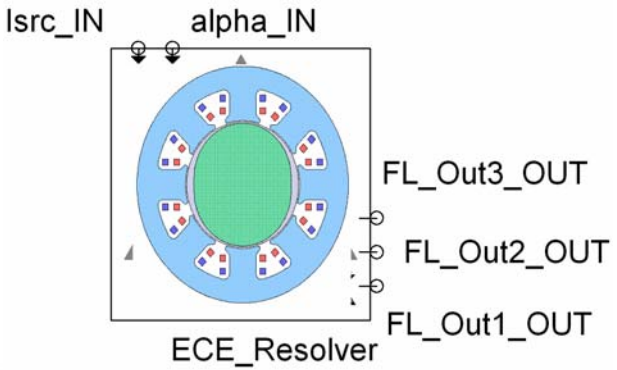
Use DSO (Distributed Analysis)
8 Machines were used
Simulation Time = **9 Hours 10 Minutes**

Almost 6 Times!

Create an Equivalent Circuit Model for the Resolver



Variation	ISrc	alpha	Matrix1.MagFlux(Out1):...	Matrix1.MagFlux(Out2):...	Matrix1.MagFlux(Sourc...	Torq
19	2.23684210526316	0deg	-0.00301110014480 73...	4.91388773970795e-0...	0.0164237739003006...	-2.204
20	2.5	0deg	-0.00336534724823 77...	5.49199221353579e-0...	0.0183559826429141...	-2.753
21	-2.5	0.5deg	0.00335715350787347...	-6.10334820072163e-0...	-0.0183226757406397...	4.117
22	-2.23684210526316	0.5deg	0.00300376890363 35...	-5.46089044455704e-0...	-0.0163939729881088...	3.296
23	-1.97368421052632	0.5deg	0.00265038430754638...	-4.81843270501859e-0...	-0.0144652702499072...	2.566
24	-1.71052631578947	0.5deg	0.00230073160065879...	-4.29326682496 99e-00...	-0.0125549367115618...	1.492
25	-1.44736842105263	0.5deg	0.00194677288224681...	-3.63276421368784e-0...	-0.0106234079680 34w/b	1.068
26	-1.18421052631579	0.5deg	0.00159281416914345...	-2.97226161379 28e-00...	-0.0086918792338420...	7.152
27	-0.921052631578947	0.5deg	0.00123885546038464...	-2.31175902322843e-0...	-0.0067603505072893...	4.326
28	-0.657894736842105	0.5deg	0.00088489675500457...	-1.65125643996121e-0...	-0.0048288217866774...	2.207
29	-0.394736842105263	0.5deg	0.00053093805203732...	-9.90753861895159e-0...	-0.0028972930703087...	7.947
30	-0.131578947368421	0.5deg	0.00017697935051812...	-3.30251286955439e-0...	-0.0009657643564866...	8.830
31	0.131578947368421	0.5deg	-0.0001769793505182...	3.30251286957799e-0...	0.0009657643564867 6...	8.830
32	0.394736842105263	0.5deg	-0.0005309380520372...	9.90753861892694e-0...	0.0028972930703087 5...	7.947

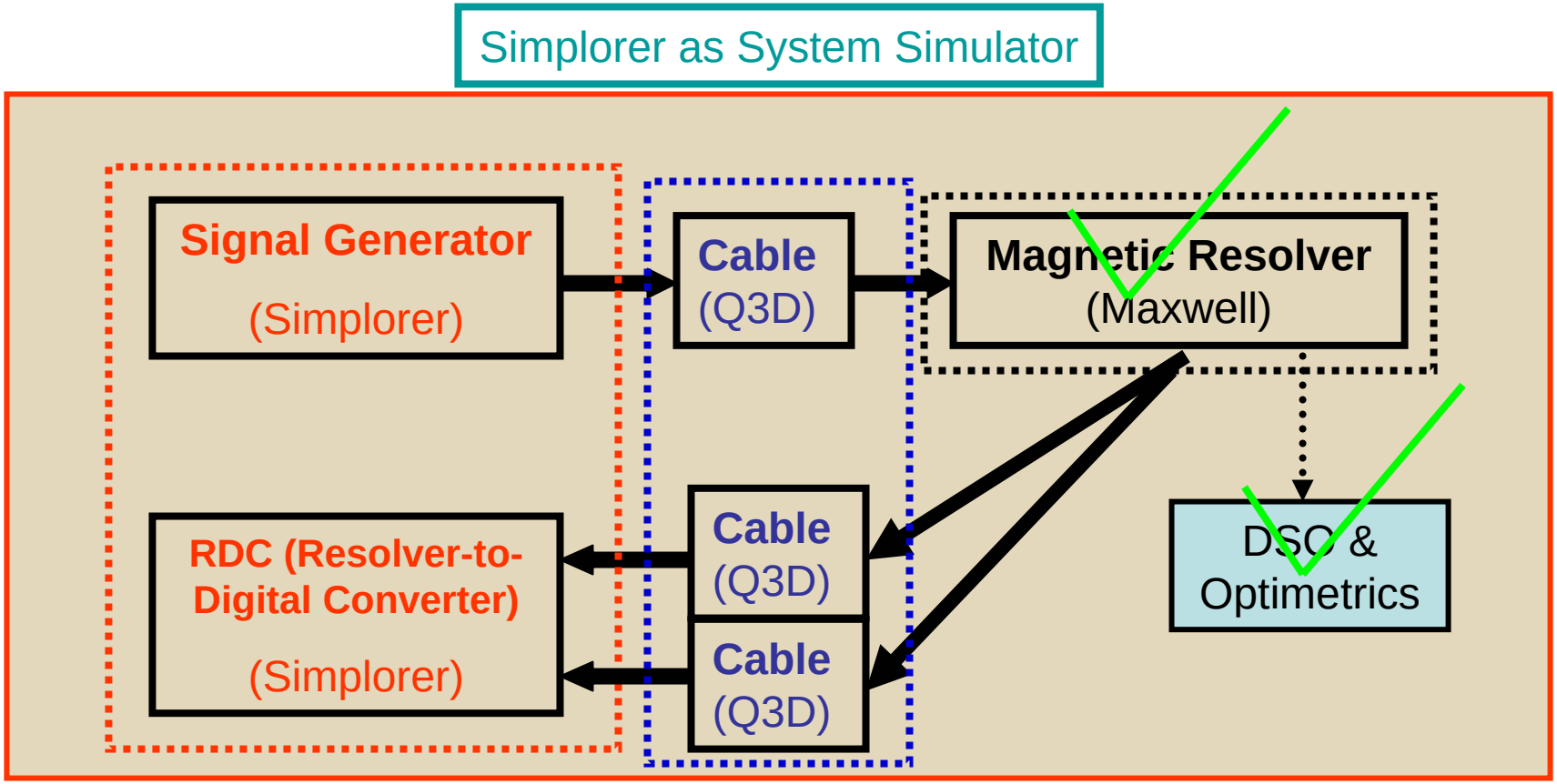


Resolver_ECE.sml

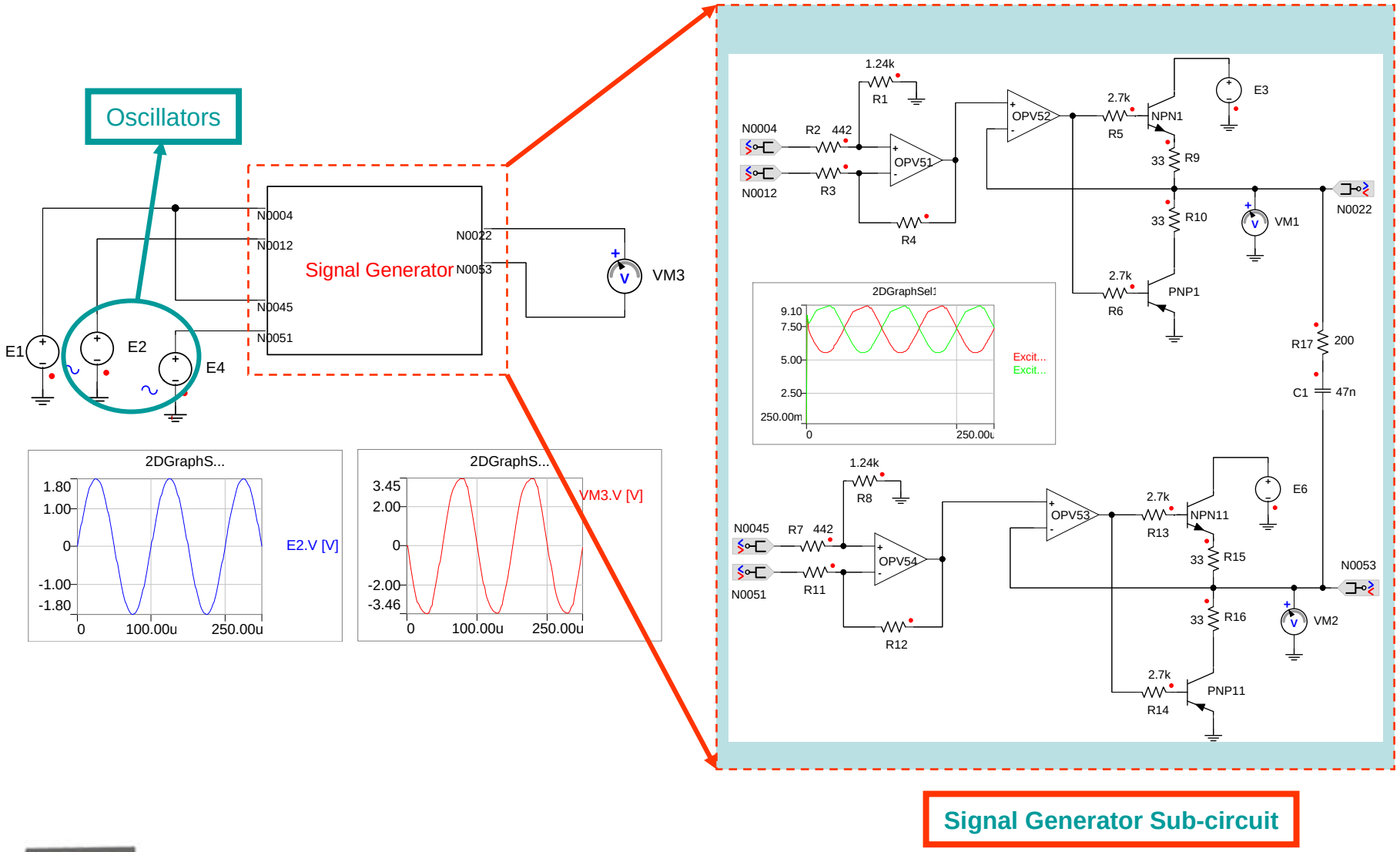
```
// BEGIN_ANSOFT_HEADER
// node N_1 FL_Out1_OUT
// node N_2 FL_Out2_OUT
// node N_3 FL_Out3_OUT
// node N_4 Isrc_IN
// node N_5 alpha_IN
// Format: SML
// Pin Layouts:
// Left:
// Right: FL_Out1_OUT FL_Out2_OUT FL_Out3_OUT
// Model: Lookup Table
// END ANSOFT HEADER
//
MODELDEF Resolver_ECE
{

// Interface Nodes
PORT real in: Isrc_IN;
PORT real in: alpha_IN;
PORT real out: FL_Out1_OUT = nOUT1.V;
PORT real out: FL_Out2_OUT = nOUT2.V;
PORT real out: FL_Out3_OUT = nOUT3.V;

// Extra Input Calculations
INTERN E Ein1 N1:=GND, N2:=nIN1 \
 (EMF:=Isrc_IN, AC_MAG:=0, PARTDERIV:=1);
INTERN VM Vin1 N1:=nIN1, N2:=GND;
INTERN E Ein2 N1:=GND, N2:=nIN2 \
 (EMF:=alpha_IN, AC_MAG:=0, PARTDERIV:=1);
INTERN VM Vin2 N1:=nIN2, N2:=GND;

// Extra Output Calculations
INTERN VM Vout1 N1:=nOUT1, N2:=GND;
INTERN VM Vout2 N1:=nOUT2, N2:=GND;
INTERN VM Vout3 N1:=nOUT3, N2:=GND;

// Piecewise-Linear Lookup Table
INTERN NDSRC Ptable N0:=nOUT1, N1:=GND, N2:=nOUT2, N3:=GND, \
 N4:=nOUT3, N5:=GND \
 (QUANT:={nIN1.V, nIN2.V}, \
 SRC:={VSRC, VSRC, VSRC}, \
 TableData:=".MODEL test pwl TABLE={ \
 20, -2.5, -2.23684, -1.97368, -1.71053, -1.44737, \
 -1.18421, -0.921053, -0.657895, -0.394737, -0.131579, 0.131579, \
 0.394737, 0.657895, 0.921053, 1.18421, 1.44737, 1.71053, \
 1.97368, 2.23684, 2.5, 0, 181, 0, \
 0.5, 1, 1.5, 2, 2.5, 3, \
 3.5, 4, 4.5, 5, 5.5, 6, \
 6.5, 7, 7.5, 8, 8.5, 9, \
 9.5, 10, 10.5, 11, 11.5, 12, \
 12.5, 13, 13.5, 14, 14.5, 15, \
 15.5, 16, 16.5, 17, 17.5, 18, \
 18.5, 19, 19.5, 20, 20.5, 21, \
 21.5, 22, 22.5, 23, 23.5, 24, \
 24.5, 25, 25.5, 26, 26.5, 27, \
 27.5, 28, 28.5, 29, 29.5, 30, \
```

Resolver System Simulation

Simplorer, Q3D, Maxwell, DSO, Optimetrics



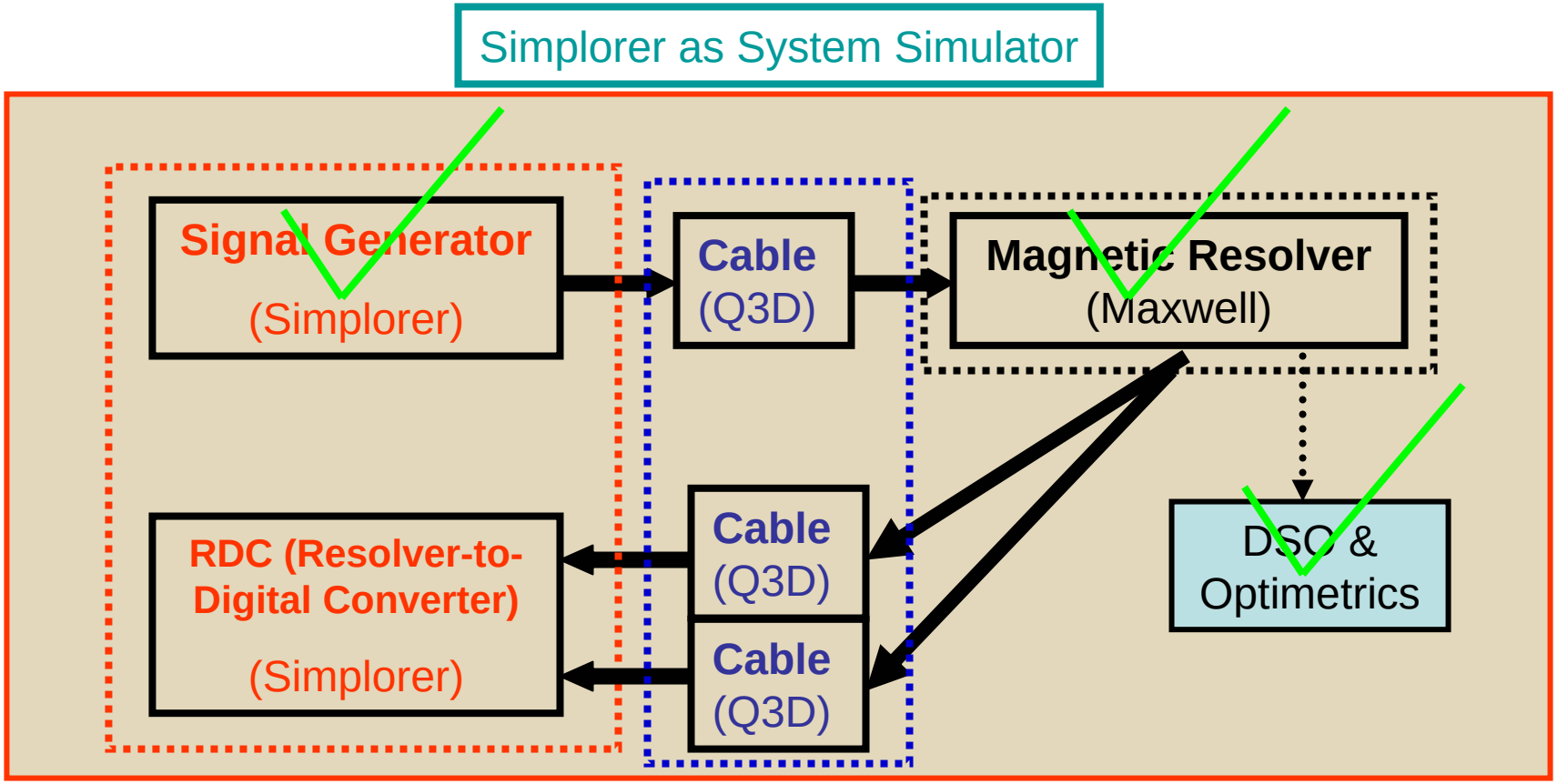
Resolver Excitation Signal Generator



Signal Generator Sub-circuit

Resolver System Simulation

Simplorer, Q3D, Maxwell, DSO, Optimetrics



Resolver-to-Digital Converter

Classical RDC Algorithm

Resolver:

V_excitation = U1*sin(2*PI*Freq*t)

V_Out_Sin = U2*sin(2*PI*Freq*t)*sin(Thita)

V_Out_Cos = U2*sin(2*PI*Freq*t)*cos(Thita)

RDC:

90 Degree Phase shift:

V_Out_Sin_1 = U2*sin(2*PI*Freq*t+90deg)*sin(Thita)

= U2*cos(2*PI*Freq)*sin(Thita)

Summation:

V_sc = V_Out_Sin_1 + V_Out_Cos

= U2_2 *sin(2*PI*Freq*t + Thita)

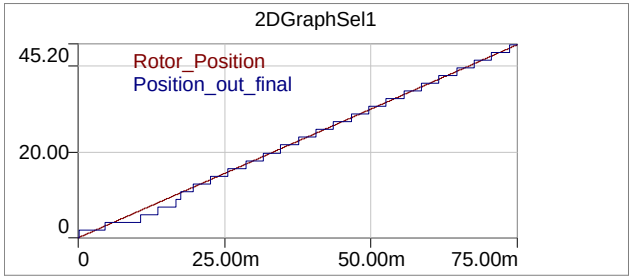
Magnitude Match:

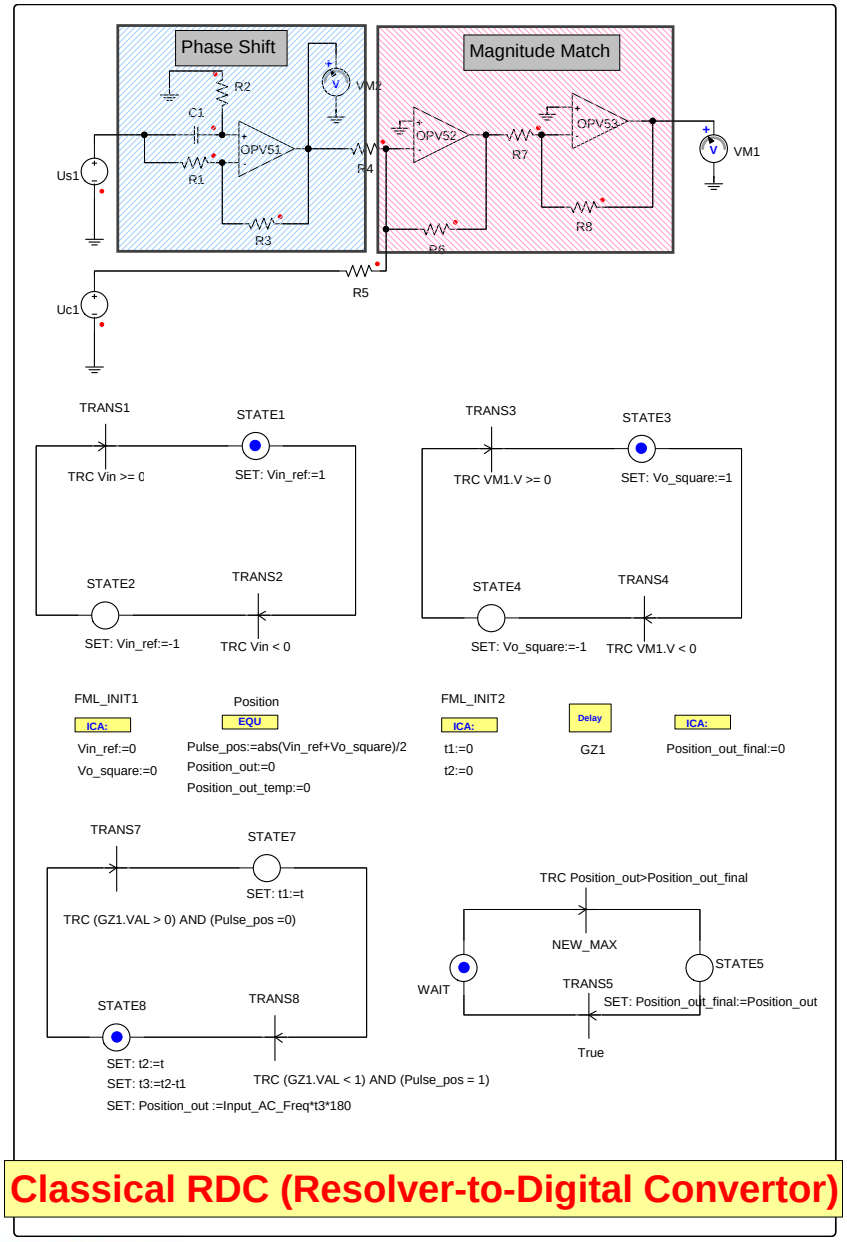
V_sc_1 = U1 *sin(2*PI*Freq*t + Thita)

Comparison:

V_excitation = U1*sin(2*PI*Freq*t)

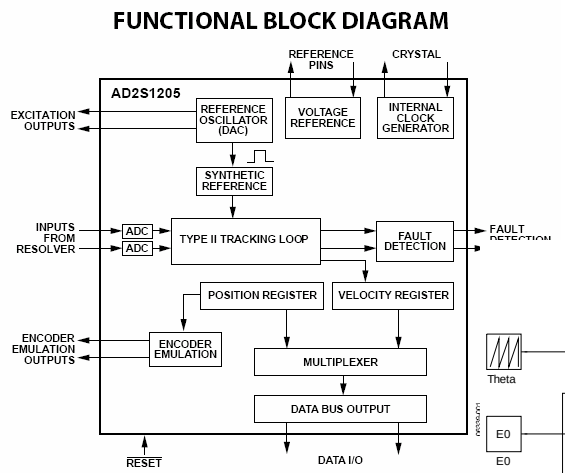
V_sc_1 = U1 *sin(2*PI*Freq*t + Thita)



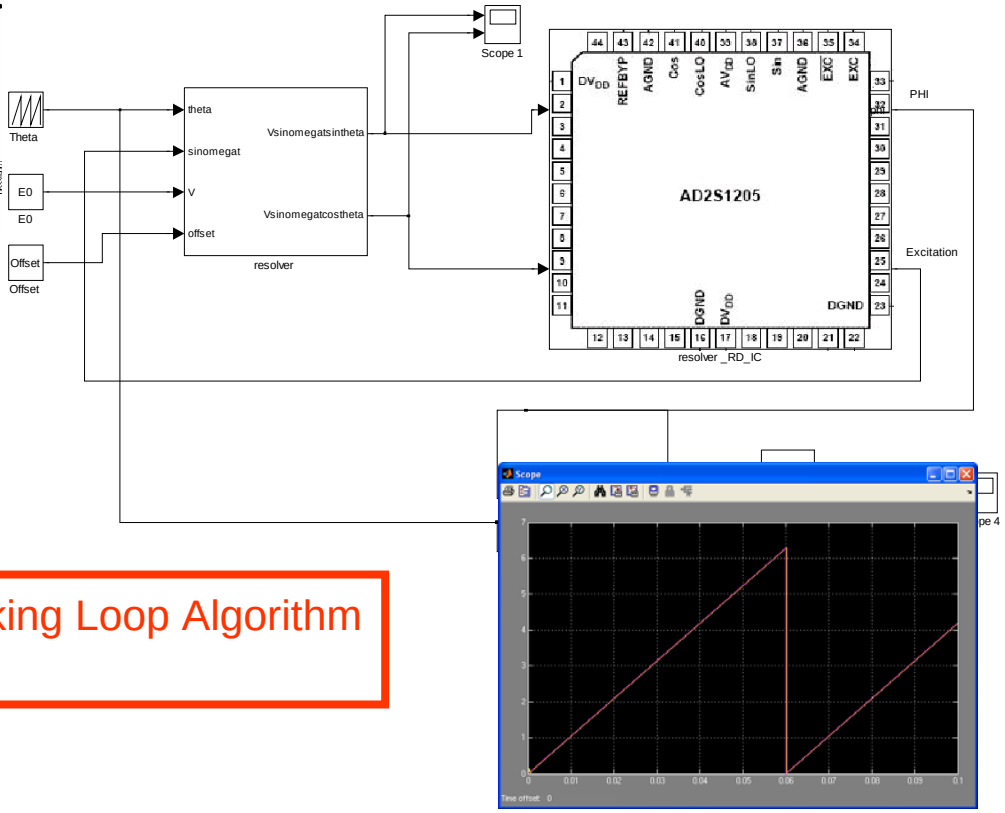


Classical RDC (Resolver-to-Digital Convertor)

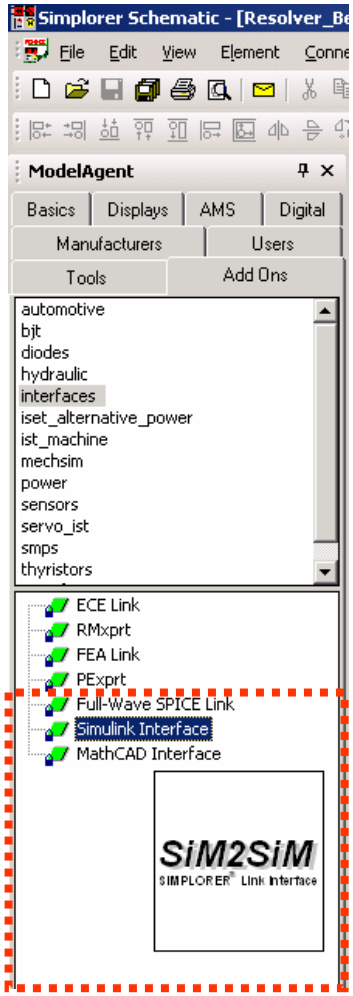
Resolver-to-Digital Converter (continued)



(Refer to Analog Devices AD2S1205 Specifications and Application Notes)

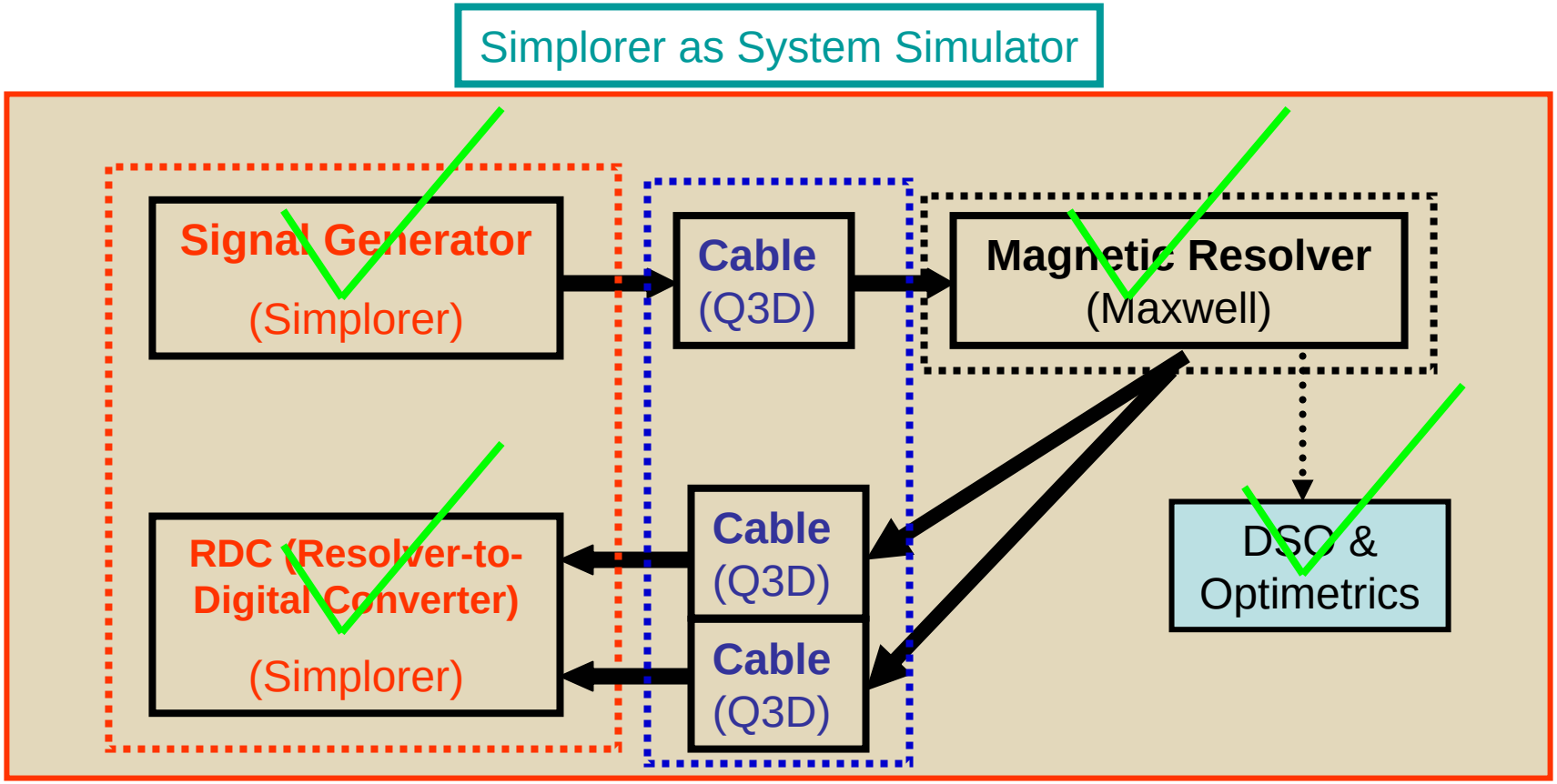


Type II Position Tracking Loop Algorithm in Matlab/SIMULINK

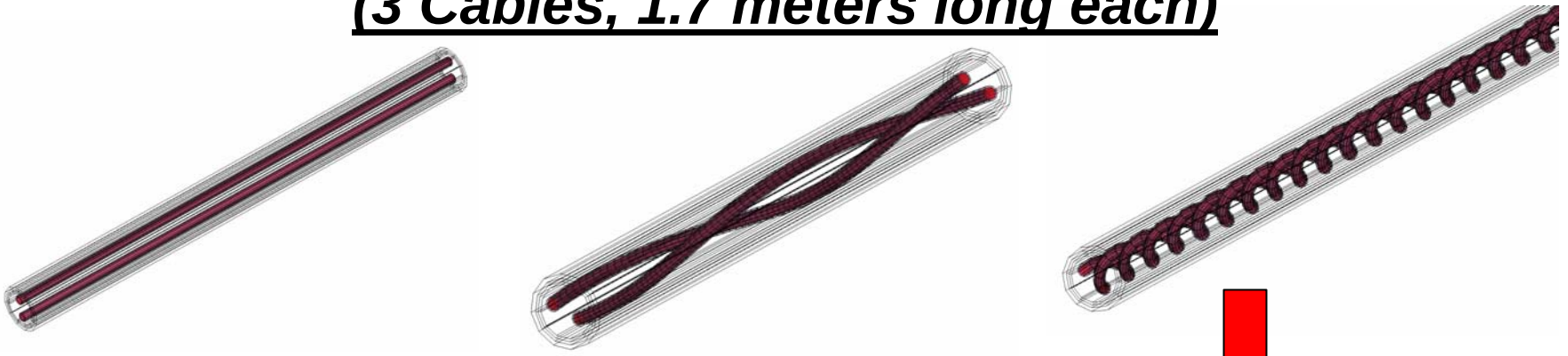


Resolver System Simulation

Simplorer, Q3D, Maxwell, DSO, Optimetrics



Resolver Cable Paracitics Extraction (3 Cables, 1.7 meters long each)



Straight -> Twist -> Multiple Twists

Name	Value	Unit
Copper_Segment	12	
Copper_Distance	1	mm
Copper_Radius	0.2	mm
Cable_Length	Number_of_Twist/Twist_Per_Meter*1000mm	
Twist_Per_Meter	35	
Number_of_Twist	6	
Copper_Insulation	0.05	mm
Total_Length	1700	mm
Scale_Factor	Total_Length/Cable_Length/1000mm	
Cable_Insu_ID	2.2	mm
Cable_Insu_OD	2.5	mm
Cable_Shield_OD	2	mm
Cable_Shield_ID	1.8	mm

All Parameterized for Optimization

Solutions: Resolver_Cable - 3_Six_Straight

Design Variation: ' Number_of_Twist='6' Scale_Factor='9.91666666666667' Total_Length='1700mm' Twist_Per_Me

Simulation: Setup1 | LastAdaptive | AC P

Matrix | Convergence | Profile

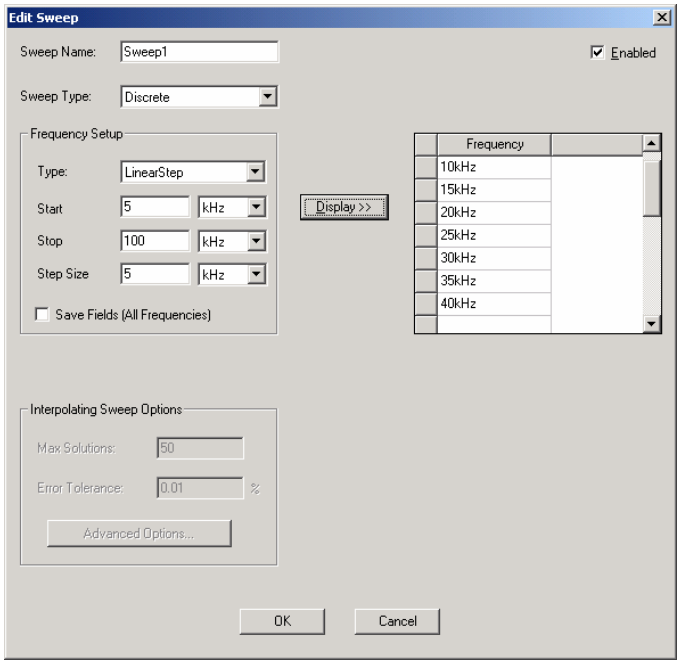
Resistance Units: Ohm | Matrix

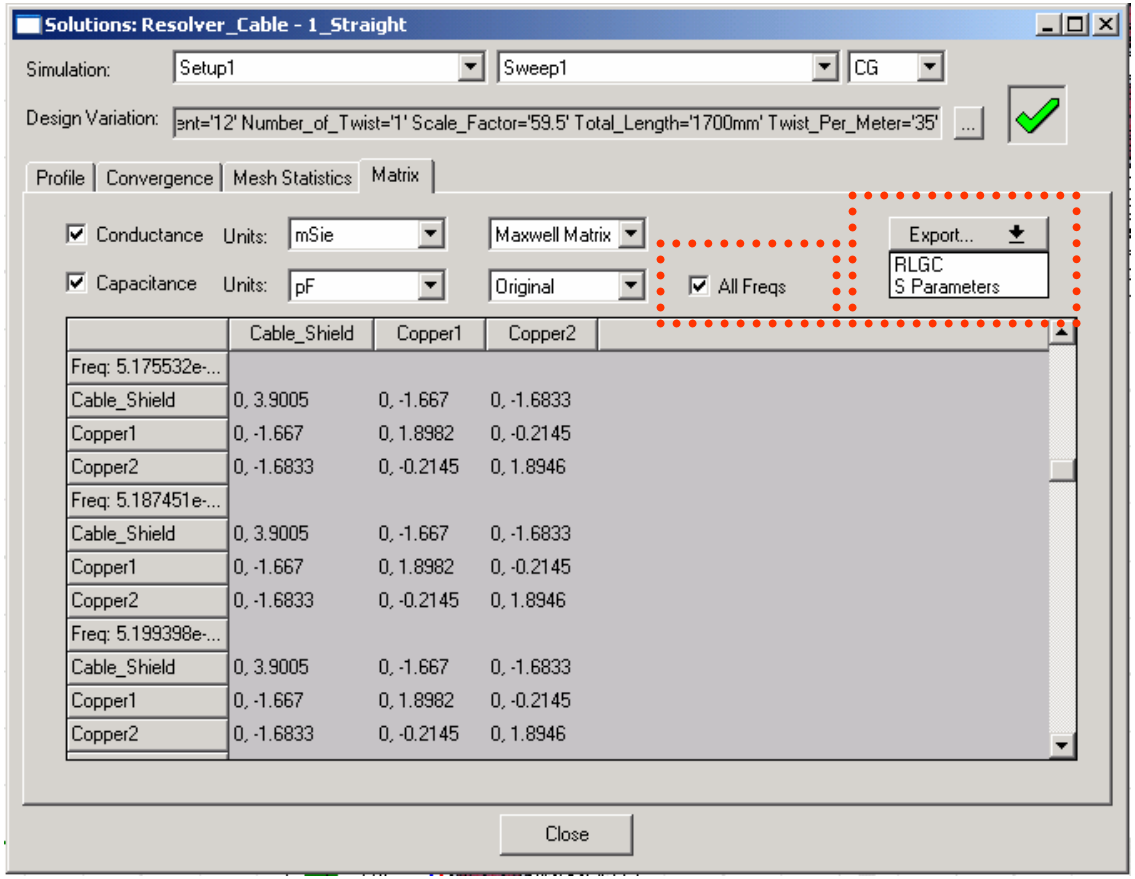
Inductance Units: nH | Original | Export...

	Cable_Shield:Source1	Copper1:Source2	Copper2:Source3
Cable_Shield:Source1	0.0018159, 162.89	0.0018241, 161.6	0.0018298, 161.97
Copper1:Source2	0.0018241, 161.6	0.014135, 195.27	0.0034835, 163.82
Copper2:Source3	0.0018298, 161.97	0.0034835, 163.82	0.014036, 196.12

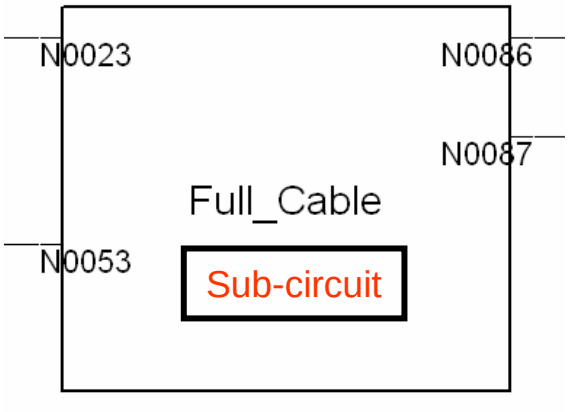
RLC Matrix

Resolver Cable Paracitics Extraction (Frequency-dependent Model Extraction)

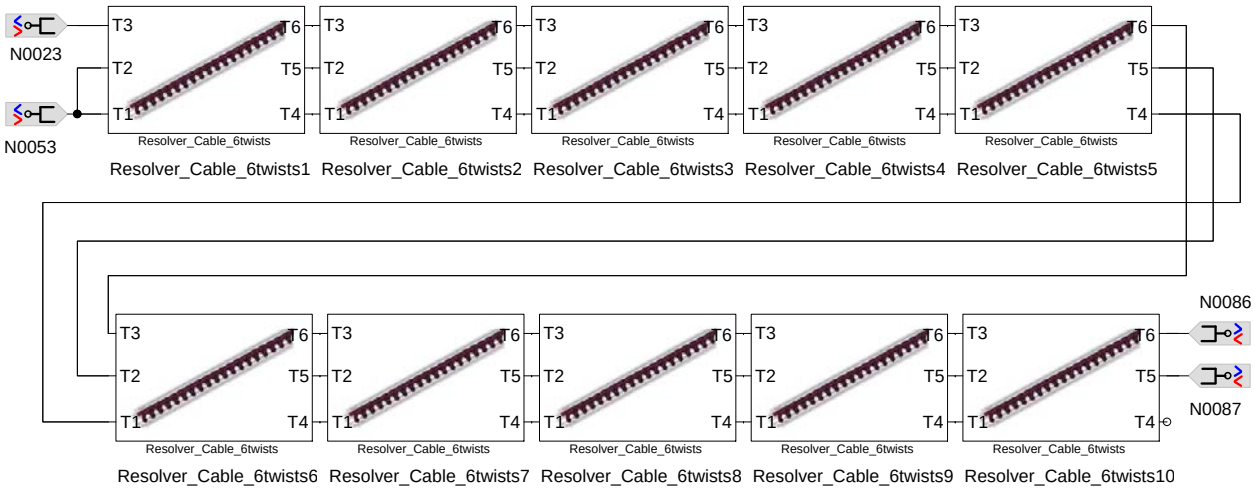




Resolver Cable Paracitics Extraction (3 Cables, 1.7 meters long each)



Each Segment is 0.17 meters long, consists of 6 twists

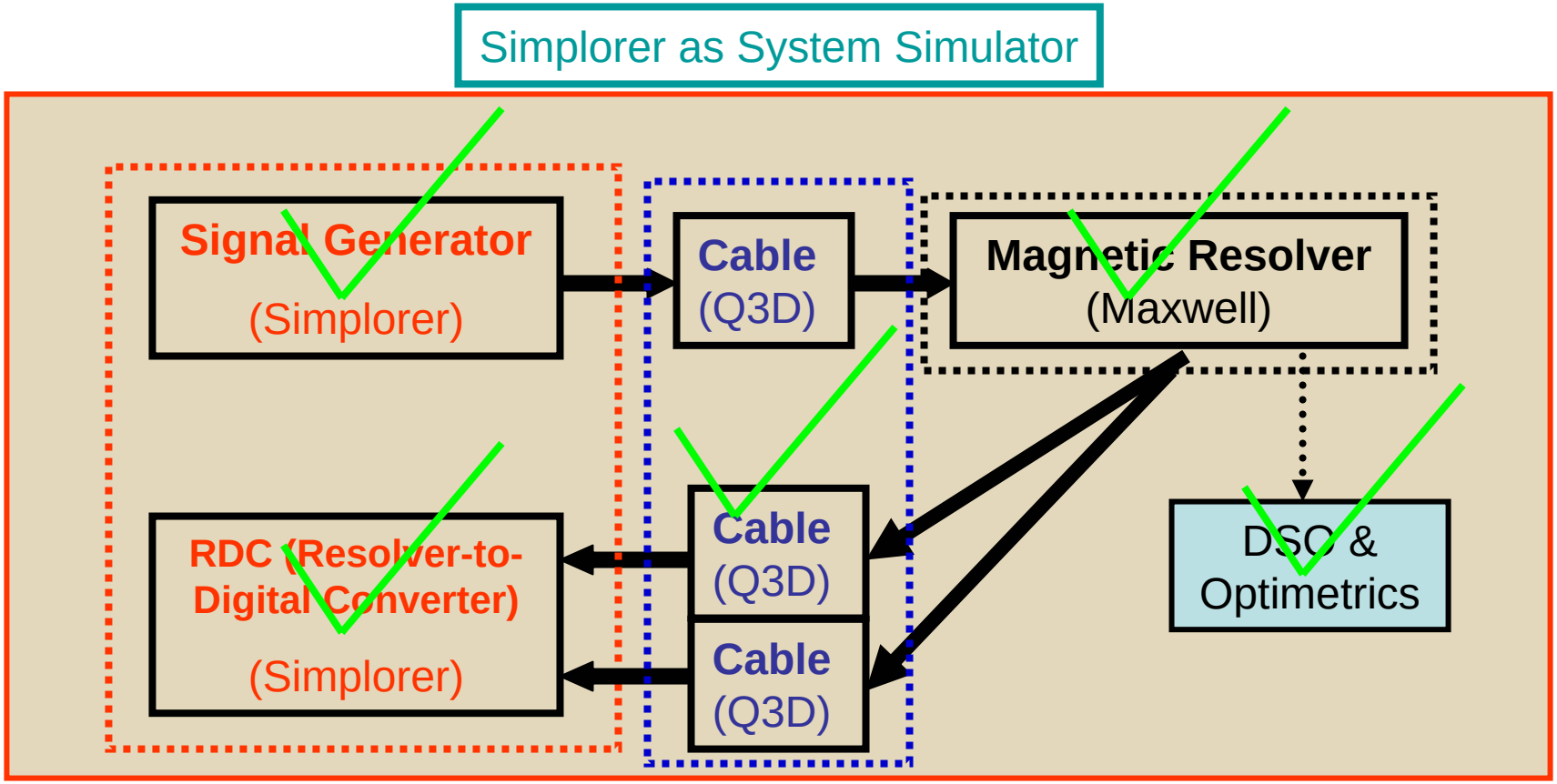


Resolver_Cable_V8.sml

```
// BEGIN ANSOFT HEADER
// node T1    Cable_Shield:Source1
// node T2    Copper1:Source2
// node T3    Copper2:Source3
// node T4    Cable_Shield:Sink1
// node T5    Copper1:Sink2
// node T6    Copper2:Sink3
//  Project: Resolver_Cable_V8
//   Design: 1_Straight
//   Format: Simplorer SML
//   Topckt: Resolver_Cable_V8
//     Left: T1 T2 T3
//    Right: T4 T5 T6
//  Creator: Ansoft Q3D Extractor 8.0
//     Date: Fri Sep 07 09:26:23 2007
//    Notes:
// END ANSOFT HEADER

#MODELDEF Resolver_Cable_V8
{
PORT electrical: T1 ;
PORT electrical: T2 ;
PORT electrical: T3 ;
PORT electrical: T4 ;
PORT electrical: T5 ;
PORT electrical: T6 ;
#MODEL Resolver_Cable_V8_half XZhalf1 T1:=T1, T2:=T2, T3:=T3, T4:=T7, T5:=T8, \
T6:=T9 ();
#MODEL Resolver_Cable_V8_parlel XY1 T1:=T7, T2:=T8, T3:=T9 ();
#MODEL Resolver_Cable_V8_half XZhalf2 T1:=T7, T2:=T8, T3:=T9, T4:=T4, T5:=T5, \
T6:=T6 ();

#MODELDEF Resolver_Cable_V8_half
{
PORT electrical: T1 ;
PORT electrical: T2 ;
PORT electrical: T3 ;
PORT electrical: T4 ;
PORT electrical: T5 ;
PORT electrical: T6 ;
INTERN AM V1 N1:=T1, N2:=T7 ( ) ;
INTERN AM V2 N1:=T2, N2:=T8 ( ) ;
INTERN AM V3 N1:=T3, N2:=T9 ( ) ;
INTERN R R1 N1:=T7, N2:=T10 ( R:=0.00080659846 ) ;
INTERN R R2 N1:=T8, N2:=T11 ( R:=0.0031969729 ) ;
INTERN R R3 N1:=T9, N2:=T12 ( R:=0.0031981392 ) ;
INTERN II F1_2 N1:=T10, N2:=T7 ( QUANT:=V2.I, FACT:= 0.179727 ) ;
INTERN II F1_3 N1:=T10, N2:=T7 ( QUANT:=V3.I, FACT:= 0.179191 ) ;
INTERN II F2_1 N1:=T11, N2:=T8 ( QUANT:=V1.I, FACT:= 0.0453453 ) ;
INTERN II F2_2 N1:=T11, N2:=T8 ( QUANT:=V3.I, FACT:= 0.0927265 ) ;
INTERN II F3_1 N1:=T12, N2:=T9 ( QUANT:=V1.I, FACT:= 0.0451936 ) ;
INTERN II F3_2 N1:=T12, N2:=T9 ( QUANT:=V2.I, FACT:= 0.0926927 ) ;
INTERN L L1 N1:=T10, N2:=T4 ( L:=0.5146892e-009 ) ;
INTERN L L2 N1:=T11, N2:=T5 ( L:=1.1682075e-008 ) ;
INTERN L L3 N1:=T12, N2:=T6 ( L:=1.1608523e-008 ) ;
INTERN M M1_2 ( L1:=L1.L, L2:=L2.L, K:=0.858496 ) ;
INTERN M M1_3 ( L1:=L1.L, L2:=L3.L, K:=0.859014 ) ;
INTERN M M2_3 ( L1:=L2.L, L2:=L3.L, K:=0.753119 ) ;
}

#MODELDEF Resolver_Cable_V8_parlel
{
PORT electrical: T1 ;
PORT electrical: T2 ;
PORT electrical: T3 ;
INTERN C C1_0 N1:=T1, N2:=GND ( C:=5.4236151e-013 ) ;
INTERN C C1_2 N1:=T1, N2:=T2 ( C:=1.6498764e-012 ) ;
INTERN C C1_3 N1:=T1, N2:=T3 ( C:=1.6540198e-012 ) ;
INTERN C C2_0 N1:=T2, N2:=GND ( C:=9.7627146e-015 ) ;
INTERN C C2_3 N1:=T2, N2:=T3 ( C:=2.1497155e-013 ) ;
INTERN C C3_0 N1:=T3, N2:=GND ( C:=9.9849619e-015 ) ;
}
}
```

Resolver System Simulation

Simplorer, Q3D, Maxwell, DSO, Optimetrics



Resolver Behavioral Model

Initialization

EQU

Input_AC_Mag := 1
Input_AC_Freq:=12k
Conductor_Ratio:=0.
Number_of_Rotor_Poles :=
Rotor_Speed :=10(
Rotor_Position := Rotor_Speed *(360/60) * t
Tend := 45/(Rotor_Speed*(360/60))
Hmin := 1/Input_AC_Freq/100
Hmax := Hmi

Excitation

EQU

Vin := Input_AC_Mag * sin(2*PI*Input_AC_Freq*t)

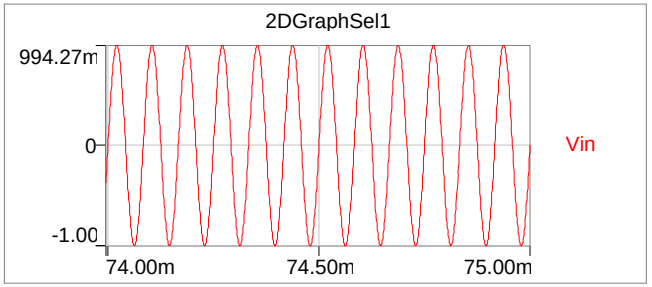
Resolver_Outpu

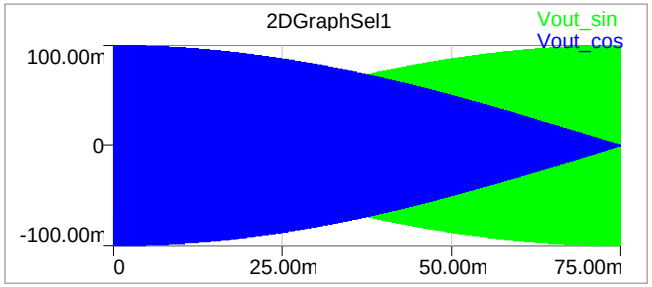
EQU

Vout_sin := Conductor_Ratio * sin(Number_of_Rotor_Poles*Rotor_Position*(PI/180))*V
Vout_cos := Conductor_Ratio * cos(Number_of_Rotor_Poles*Rotor_Position*(PI/180))*V

V_excitation = U1*sin(2*PI*Freq*t)
V_Out_Sin = U2*sin(2*PI*Freq*t)*sin(Thita)
V_Out_Cos = U2*sin(2*PI*Freq*t)*cos(Thita)

Resolver





Resolver and RDC Model

Initialization

EQU

Input_AC_Mag := 1
Input_AC_Freq:=12k
Conductor_Ratio:=0.1
Number_of_Rotor_Poles :=4
Rotor_Speed :=100
Rotor_Position := Rotor_Speed *(360/60) * t
Tend := 45/(Rotor_Speed*(360/60))
Hmin := 1/Input_AC_Freq/100
Hmax := Hmir

Excitation

EQU

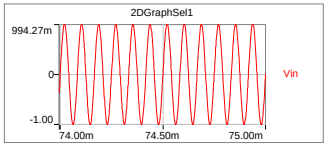
Vin := Input_AC_Mag * sin(2*PI*Input_AC_Freq*t)

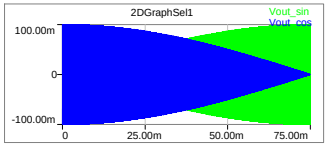
Resolver_Outpu

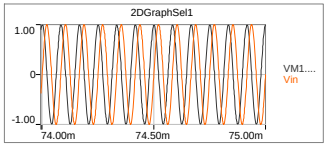
EQU

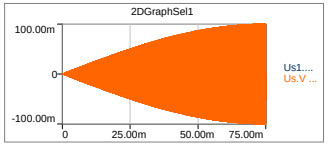
Vout_sin := Conductor_Ratio * sin(Number_of_Rotor_Poles*Rotor_Position*(PI/180))*Vir
Vout_cos := Conductor_Ratio * cos(Number_of_Rotor_Poles*Rotor_Position*(PI/180))*Vir

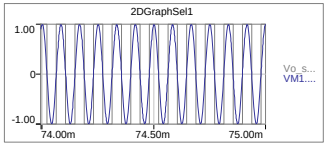
Resolver

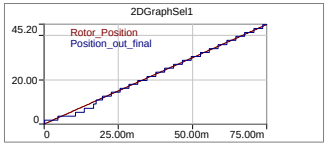


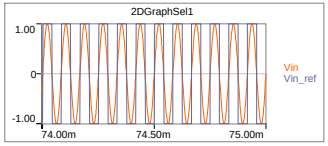


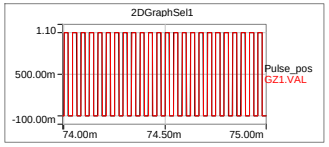




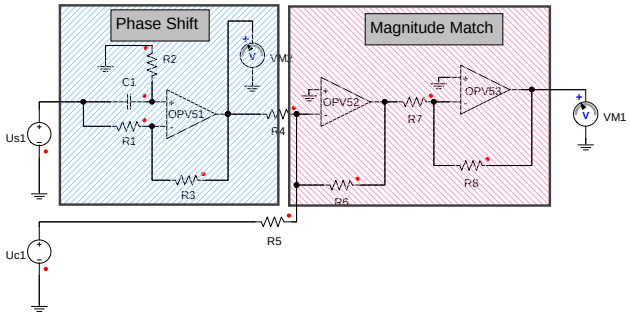


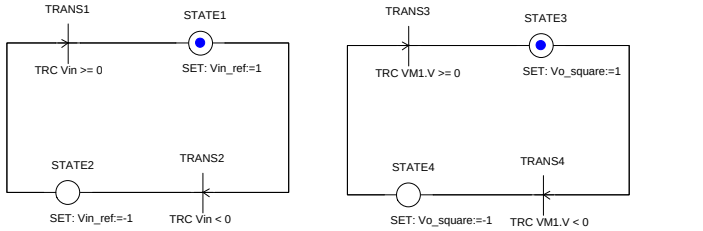


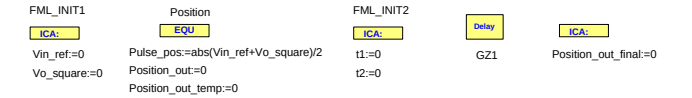


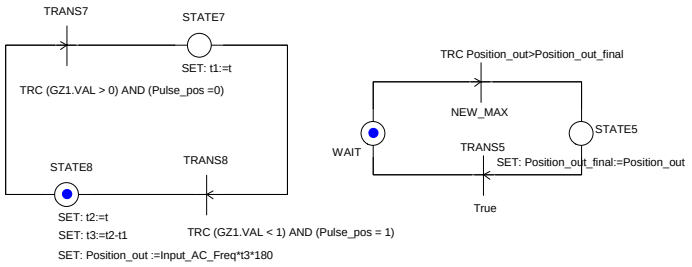


Resolver and RDC Behavial Model



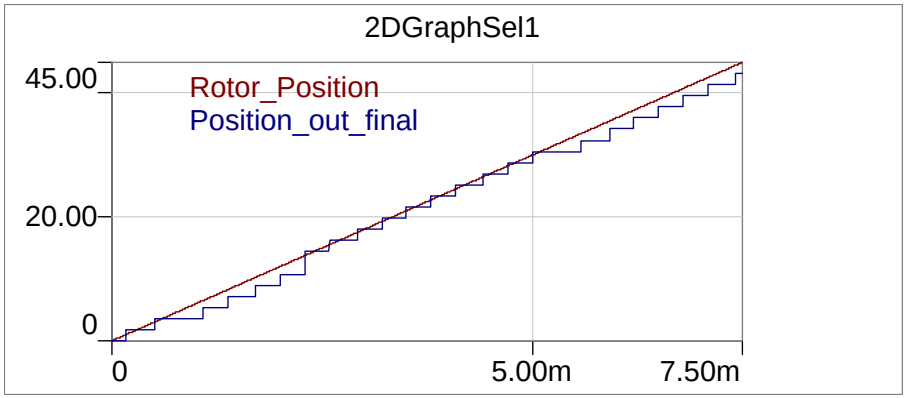




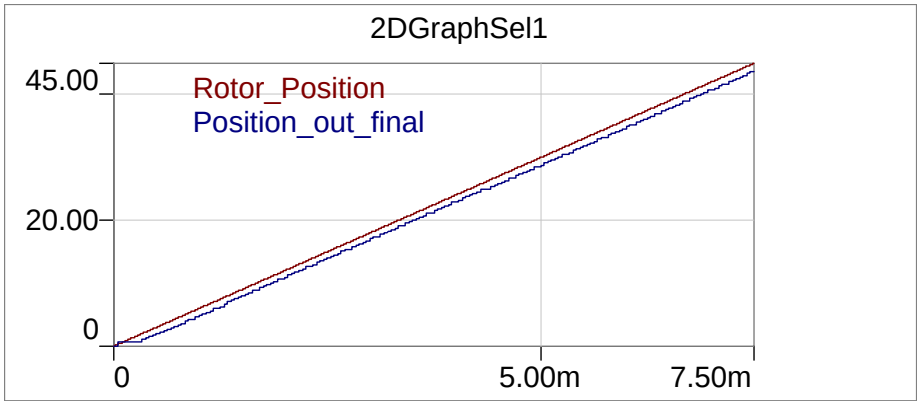


Classical RDC (Resolver-to-Digital Convertor

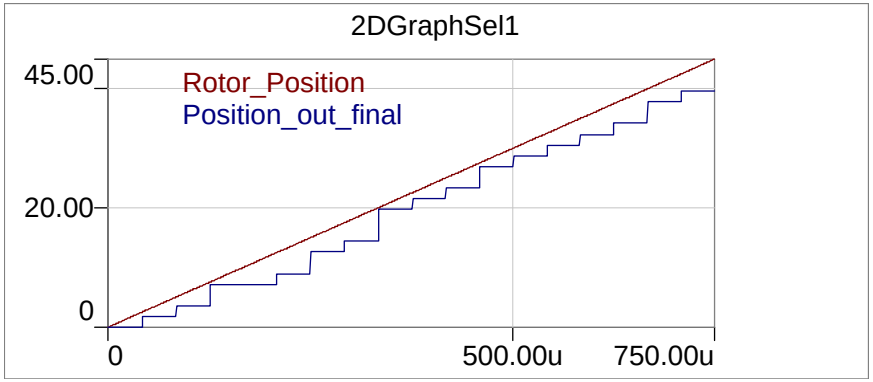
Position Output Accuracy



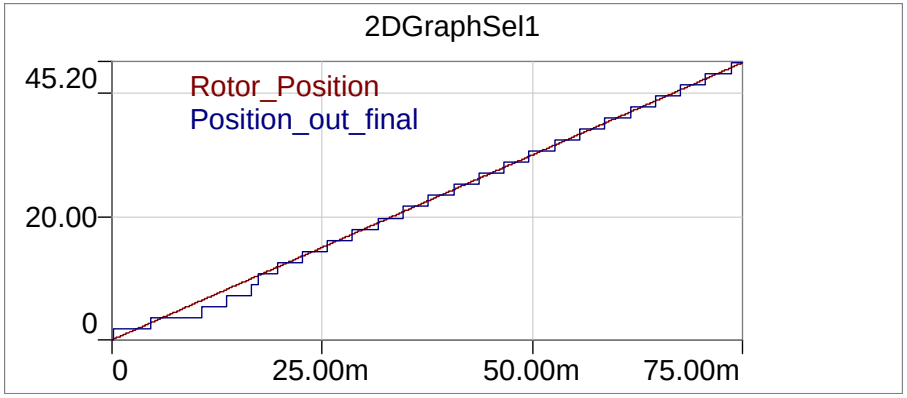
12k Hz excitation, 1,000RPM speed, 0.1us sampling time



12k Hz excitation, 1,000RPM speed, 0.01us sampling time

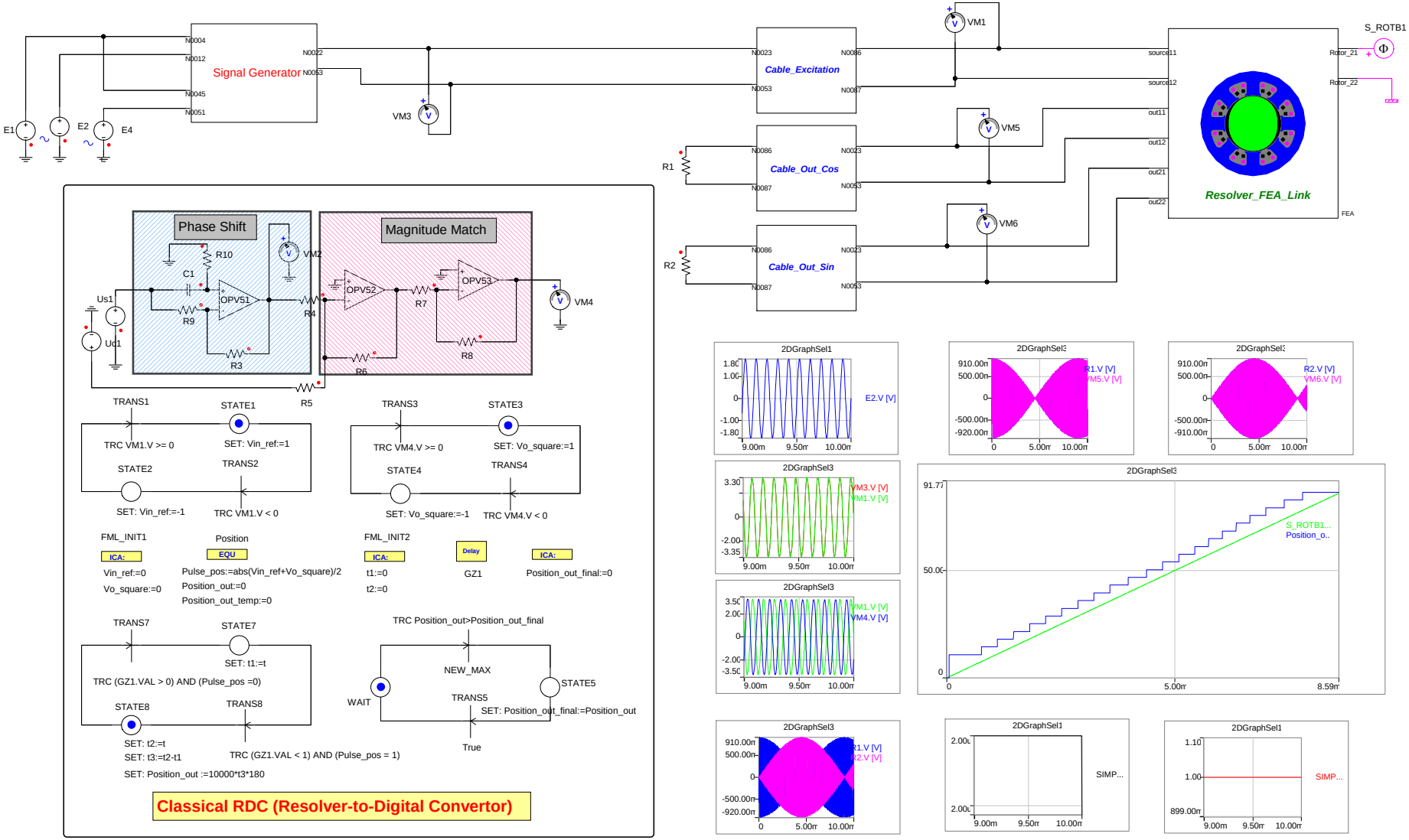


12k Hz excitation, 10,000RPM speed, 0.1us sampling time

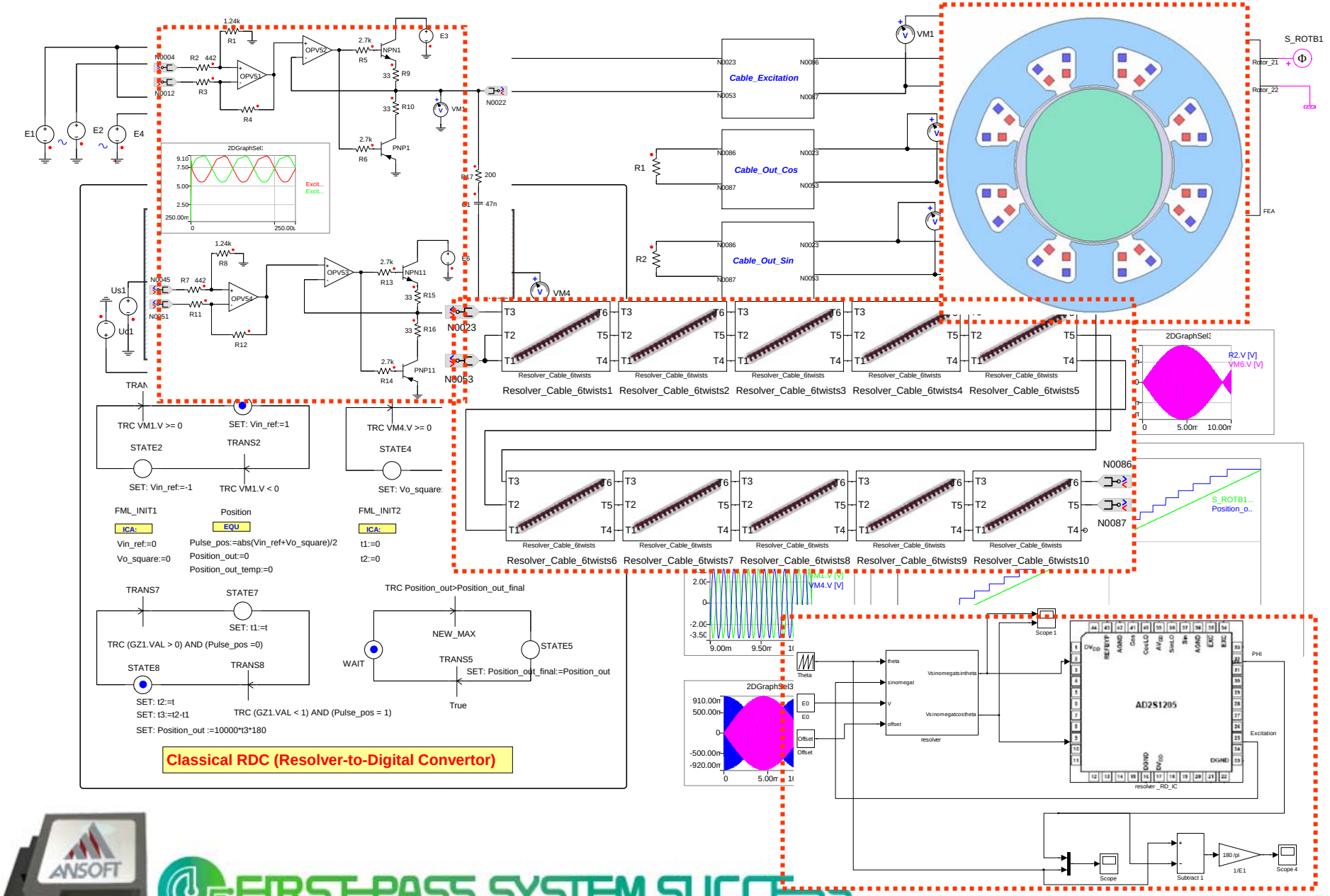


12k Hz excitation, 100RPM speed, 0.1us sampling time

Resolver System Integration



Resolver System Integration

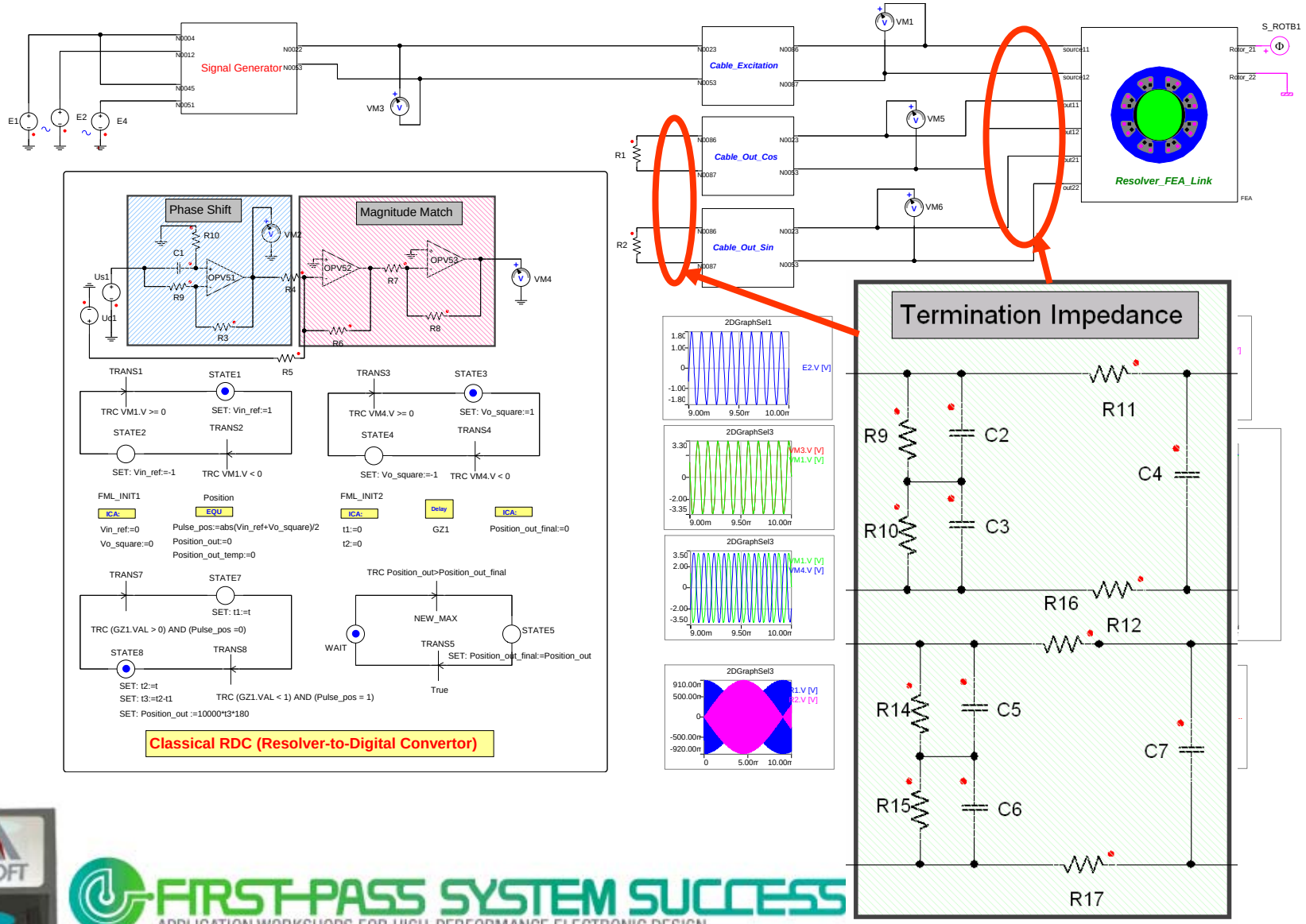


Conclusions

- Resolver Deserves More Attention for Applications where Rugged, High-accuracy Position Sensing is Needed
- A Systematic Approach is Necessary for Signal Generator / Resolver / Cable / Resolver-to-Digital Converter System Optimization
- Simplore as a Multi-level / Multi-domain System Simulator is an Ideal Tool for Applications where Electric Circuitry, Field Simulation and Paracitics are Involved
- Each Tool (Simplorer / Maxwell / Q3D) can be Used as a Stand-alone Design Tool to Optimize Components (Signal Generator / RDC Algorithm / Resolver / Cable) in the System
- This Systematic Approach Ensures Engineers from both Sides of Component Design / System Integration to be Successful

Future Work:

1. Add Termination Impedance, to take into account the harmonics and transmission line reflection



Future Work:

2. Replace the classical RDC with Type II Position Tracking mode