
Lime Microsystems Limited

Surrey Tech Centre
Occam Road
The Surrey Research Park
Guildford, Surrey GU2 7YG
United Kingdom



Tel: +44 (0) 1483 685 063
Fax: +44 (0) 1428 656 662
e-mail: enquiries@limemicro.com

S-parameter characterisation of LMS7002M Field Programmable RF MIMO Transceiver Integrated Circuit

Chip version:	LMS7002M
Chip revision:	01
Document version:	01
Document revision:	05
Last modified:	24/08/2015 13:40:00

Table of Contents

1. Introduction.....	8
1.1 Principles of S-parameter Measurements.....	8
2. Design of the Lime Characterization Boards	10
2.1 S-parameter Files.....	10
3. Example Simulation	15
3.1 Simulation of the LMS7002M Evaluation Board LNAWA input.	15
3.2 Common difficulties with simulating with S-parameters	16
3.3 S-parameters and TX Output.....	17
4. Measured S-parameter Graphs	18
4.1 LNAH channel A sample 1	19
4.2 LNAH channel A sample 2	24
4.3 LNAH Channel A Sample 3.....	29
4.4 LNAH Channel B Sample 2.....	34
4.5 LNAH Channel B Sample 3.....	39
4.6 LNAL Channel A Sample 1	44
4.7 LNAL Channel A Sample 2	51
4.8 LNAL Channel A Sample 3	58
4.9 LNAL Channel B Sample 1	64
4.10 LNAL Channel B Sample 2	71
4.11 LNAL Channel B Sample 3	78
4.12 LNAW Channel A Sample 1.....	85
4.13 LNAW Channel A Sample 2.....	91
4.14 LNAW Channel A Sample 3.....	98
4.15 LNAW Channel B Sample 1	105
4.16 LNAW Channel B Sample 2.....	112
4.17 LNAW Channel B Sample 3.....	119

List of Figures

Figure 1 LMS7002M Architecture	8
Figure 2 S-parameter Characterisation Boards.	10
Figure 3 Simulated and Measured S_{11} of LMS7002M LNALA.	15
Figure 4 Simulated variation of S_{11} of LMS7002M LNALA with LNA gain.	16
Figure 5 Simulated variation of S_{11} of LMS7002M LNALA with input capacitance code.	16
Figure 6 LNAHA Sample=1 Gain=0, Cap_Var=0.....	19
Figure 7 LNAHA Sample=1 Gain=0, Cap_Var =10.....	19
Figure 8 LNAHA Sample=1 Gain=0, Cap_Var =20.....	20
Figure 9 LNAHA Sample=1 Gain=0, Cap_Var =31.....	20
Figure 10 LNAHA Sample=1 Gain=6, Cap_Var =0.....	21
Figure 11 LNAHA Sample=1 Gain=6, Cap_Var =10.....	21
Figure 12 LNAHA Sample=1 Gain=6, Cap_Var =20.....	22
Figure 13 LNAHA Sample=1 Gain=6, Cap_Var =31.....	22
Figure 14 LNAHA Sample=1 Gain=18, Cap_Var =0.....	23
Figure 15 LNAHA Sample=1 Gain=31, Cap_Var =0.....	23
Figure 16 LNAHA Sample=2 Gain=0, Cap_Var=0.....	24
Figure 17 LNAHA Sample=2 Gain=0, Cap_Var =10.....	24
Figure 18 LNAHA Sample=2 Gain=0, Cap_Var =20.....	25
Figure 19 LNAHA Sample=2 Gain=0, Cap_Var =31.....	25
Figure 20 LNAHA Sample=2 Gain=6, Cap_Var =0.....	26
Figure 21 LNAHA Sample=2 Gain=6, Cap_Var =10.....	26
Figure 22 LNAHA Sample=2 Gain=6, Cap_Var =20.....	27
Figure 23 LNAHA Sample=2 Gain=6, Cap_Var =31.....	27
Figure 24 LNAHA Sample=2 Gain=18, Cap_Var =0.....	28
Figure 25 LNAHA Sample=2 Gain=31, Cap_Var =0.....	28
Figure 26 LNAHA Sample=3 Gain=0, Cap_Var=0.....	29
Figure 27 LNAHA Sample=3 Gain=0, Cap_Var =10.....	29
Figure 28 LNAHA Sample=3 Gain=0, Cap_Var =20.....	30
Figure 29 LNAHA Sample=3 Gain=0, Cap_Var =31.....	30
Figure 30 LNAHA Sample=3 Gain=6, Cap_Var =0.....	31
Figure 31 LNAHA Sample=3 Gain=6, Cap_Var =10.....	31
Figure 32 LNAHA Sample=3 Gain=6, Cap_Var =20.....	32
Figure 33 LNAHA Sample=3 Gain=6, Cap_Var =31.....	32
Figure 34 LNAHA Sample=3 Gain=18, Cap_Var =0.....	33
Figure 35 LNAHA Sample=3 Gain=31, Cap_Var =0.....	33
Figure 36 LNAHB Sample=2 Gain=0, Cap_Var=0.....	34
Figure 37 LNAHB Sample=2 Gain=0, Cap_Var =10.....	34
Figure 38 LNAHB Sample=2 Gain=0, Cap_Var =20.....	35
Figure 39 LNAHB Sample=2 Gain=0, Cap_Var =31.....	35
Figure 40 LNAHB Sample=2 Gain=6, Cap_Var =0.....	36
Figure 41 LNAHB Sample=2 Gain=6, Cap_Var =10.....	36
Figure 42 LNAHB Sample=2 Gain=6, Cap_Var =20.....	37
Figure 43 LNAHB Sample=2 Gain=6, Cap_Var =31.....	37
Figure 44 LNAHB Sample=2 Gain=18, Cap_Var =0.....	38
Figure 45 LNAHB Sample=2 Gain=31, Cap_Var =0.....	38
Figure 46 LNAHB Sample=3 Gain=0, Cap_Var=0.....	39
Figure 47 LNAHB Sample=3 Gain=0, Cap_Var =10.....	39

Figure 48 LNAHB Sample=3 Gain=0, Cap_Var =20	40
Figure 49 LNAHB Sample=3 Gain=0, Cap_Var =31	40
Figure 50 LNAHB Sample=3 Gain=6, Cap_Var =0	41
Figure 51 LNAHB Sample=3 Gain=6, Cap_Var =10	41
Figure 52 LNAHB Sample=3 Gain=6, Cap_Var =20	42
Figure 53 LNAHB Sample=3 Gain=6, Cap_Var =31	42
Figure 54 LNAHB Sample=3 Gain=18, Cap_Var =0	43
Figure 55 LNAHB Sample=3 Gain=31, Cap_Var =0	43
Figure 56 LNALA Sample=1 Gain=0, Cap_Var=0 Short=0	44
Figure 57 LNALA Sample=1 Gain=0, Cap_Var=0 Short=1	44
Figure 58 LNALA Sample=1 Gain=0, Cap_Var =10 Short=0	45
Figure 59 LNALA Sample=1 Gain=0, Cap_Var =10 Short=1	45
Figure 60 LNALA Sample=1 Gain=0, Cap_Var =20 Short=0	46
Figure 61 LNALA Sample=1 Gain=0, Cap_Var =20 Short=1	46
Figure 62 LNALA Sample=1 Gain=0, Cap_Var =31 Short=0	47
Figure 63 LNALA Sample=1 Gain=0, Cap_Var =31 Short=1	47
Figure 64 LNALA Sample=1 Gain=6, Cap_Var =0 Short=0	48
Figure 65 LNALA Sample=1 Gain=6, Cap_Var =10 Short=0	48
Figure 66 LNALA Sample=1 Gain=6, Cap_Var =20 Short=0	49
Figure 67 LNALA Sample=1 Gain=6, Cap_Var =31 Short=0	49
Figure 68 LNALA Sample=1 Gain=18, Cap_Var =0 Short=0	50
Figure 69 LNALA Sample=1 Gain=31, Cap_Var =0 Short=0	50
Figure 70 LNALA Sample=2 Gain=0, Cap_Var=0 Short=0	51
Figure 71 LNALA Sample=2 Gain=0, Cap_Var=0 Short=1	51
Figure 72 LNALA Sample=2 Gain=0, Cap_Var =10 Short=0	52
Figure 73 LNALA Sample=2 Gain=0, Cap_Var =10 Short=1	52
Figure 74 LNALA Sample=2 Gain=0, Cap_Var =20 Short=0	53
Figure 75 LNALA Sample=2 Gain=0, Cap_Var =20 Short=1	53
Figure 76 LNALA Sample=2 Gain=0, Cap_Var =31 Short=0	54
Figure 77 LNALA Sample=2 Gain=0, Cap_Var =31 Short=1	54
Figure 78 LNALA Sample=2 Gain=6, Cap_Var =0 Short=0	55
Figure 79 LNALA Sample=2 Gain=6, Cap_Var =10 Short=0	55
Figure 80 LNALA Sample=2 Gain=6, Cap_Var =20 Short=0	56
Figure 81 LNALA Sample=2 Gain=6, Cap_Var =31 Short=0	56
Figure 82 LNALA Sample=2 Gain=18, Cap_Var =0 Short=0	57
Figure 83 LNALA Sample=2 Gain=31, Cap_Var =0 Short=0	57
Figure 84 LNALA Sample=3 Gain=0, Cap_Var=0 Short=0	58
Figure 85 LNALA Sample=3 Gain=0, Cap_Var=0 Short=1	58
Figure 86 LNALA Sample=3 Gain=0, Cap_Var =10 Short=0	59
Figure 87 LNALA Sample=3 Gain=0, Cap_Var =20 Short=0	59
Figure 88 LNALA Sample=3 Gain=0, Cap_Var =31 Short=0	60
Figure 89 LNALA Sample=3 Gain=6, Cap_Var =0 Short=0	60
Figure 90 LNALA Sample=3 Gain=6, Cap_Var =10 Short=0	61
Figure 91 LNALA Sample=3 Gain=6, Cap_Var =20 Short=0	61
Figure 92 LNALA Sample=3 Gain=6, Cap_Var =31 Short=0	62
Figure 93 LNALA Sample=3 Gain=18, Cap_Var =0 Short=0	62
Figure 94 LNALA Sample=3 Gain=31, Cap_Var =0 Short=0	63
Figure 95 LNALB Sample=1 Gain=0, Cap_Var=0 Short=0	64
Figure 96 LNALB Sample=1 Gain=0, Cap_Var=0 Short=1	64
Figure 97 LNALB Sample=1 Gain=0, Cap_Var =10 Short=0	65

Figure 98 LNALB Sample=1 Gain=0, Cap_Var =10 Short=1	65
Figure 99 LNALB Sample=1 Gain=0, Cap_Var =20 Short=0	66
Figure 100 LNALB Sample=1 Gain=0, Cap_Var =20 Short=1	66
Figure 101 LNALB Sample=1 Gain=0, Cap_Var =31 Short=0	67
Figure 102 LNALB Sample=1 Gain=0, Cap_Var =31 Short=1	67
Figure 103 LNALB Sample=1 Gain=6, Cap_Var =0 Short=0	68
Figure 104 LNALB Sample=1 Gain=6, Cap_Var =10 Short=0	68
Figure 105 LNALB Sample=1 Gain=6, Cap_Var =20 Short=0	69
Figure 106 LNALB Sample=1 Gain=6, Cap_Var =31 Short=0	69
Figure 107 LNALB Sample=1 Gain=18, Cap_Var =0 Short=0	70
Figure 108 LNALB Sample=1 Gain=31, Cap_Var =0 Short=0	70
Figure 109 LNALB Sample=2 Gain=0, Cap_Var=0 Short=0	71
Figure 110 LNALB Sample=2 Gain=0, Cap_Var=0 Short=1	71
Figure 111 LNALB Sample=2 Gain=0, Cap_Var =10 Short=0	72
Figure 112 LNALB Sample=2 Gain=0, Cap_Var =10 Short=1	72
Figure 113 LNALB Sample=2 Gain=0, Cap_Var =20 Short=0	73
Figure 114 LNALB Sample=2 Gain=0, Cap_Var =20 Short=1	73
Figure 115 LNALB Sample=2 Gain=0, Cap_Var =31 Short=0	74
Figure 116 LNALB Sample=2 Gain=0, Cap_Var =31 Short=1	74
Figure 117 LNALB Sample=2 Gain=6, Cap_Var =0 Short=0	75
Figure 118 LNALB Sample=2 Gain=6, Cap_Var =10 Short=0	75
Figure 119 LNALB Sample=2 Gain=6, Cap_Var =20 Short=0	76
Figure 120 LNALB Sample=2 Gain=6, Cap_Var =31 Short=0	76
Figure 121 LNALB Sample=2 Gain=18, Cap_Var =0 Short=0	77
Figure 122 LNALB Sample=2 Gain=31, Cap_Var =0 Short=0	77
Figure 123 LNALB Sample=3 Gain=0, Cap_Var=0 Short=0	78
Figure 124 LNALB Sample=3 Gain=0, Cap_Var=0 Short=1	78
Figure 125 LNALB Sample=3 Gain=0, Cap_Var =10 Short=0	79
Figure 126 LNALB Sample=3 Gain=0, Cap_Var =10 Short=1	79
Figure 127 LNALB Sample=3 Gain=0, Cap_Var =20 Short=0	80
Figure 128 LNALB Sample=3 Gain=0, Cap_Var =20 Short=1	80
Figure 129 LNALB Sample=3 Gain=0, Cap_Var =31 Short=0	81
Figure 130 LNALB Sample=3 Gain=0, Cap_Var =31 Short=1	81
Figure 131 LNALB Sample=3 Gain=6, Cap_Var =0 Short=0	82
Figure 132 LNALB Sample=3 Gain=6, Cap_Var =10 Short=0	82
Figure 133 LNALB Sample=3 Gain=6, Cap_Var =20 Short=0	83
Figure 134 LNALB Sample=3 Gain=6, Cap_Var =31 Short=0	83
Figure 135 LNALB Sample=3 Gain=18, Cap_Var =0 Short=0	84
Figure 136 LNALB Sample=3 Gain=31, Cap_Var =0 Short=0	84
Figure 137 LNAWA Sample=1 Gain=0, Cap_Var=0 Short=0.....	85
Figure 138 LNAWA Sample=1 Gain=0, Cap_Var=0 Short=1	85
Figure 139 LNAWA Sample=1 Gain=0, Cap_Var =10 Short=0.....	86
Figure 140 LNAWA Sample=1 Gain=0, Cap_Var =10 Short=1	86
Figure 141 LNAWA Sample=1 Gain=0, Cap_Var =20 Short=0.....	87
Figure 142 LNAWA Sample=1 Gain=0, Cap_Var =20 Short=1	87
Figure 143 LNAWA Sample=1 Gain=0, Cap_Var =31 Short=0.....	88
Figure 144 LNAWA Sample=1 Gain=0, Cap_Var =31 Short=1	88
Figure 145 LNAWA Sample=1 Gain=6, Cap_Var =0 Short=0.....	89
Figure 146 LNAWA Sample=1 Gain=18, Cap_Var =0 Short=0.....	89
Figure 147 LNAWA Sample=1 Gain=31, Cap_Var =0 Short=0.....	90

Figure 148 LNAWA Sample=2 Gain=0, Cap_Var=0 Short=0	91
Figure 149 LNAWA Sample=2 Gain=0, Cap_Var=0 Short=1	91
Figure 150 LNAWA Sample=2 Gain=0, Cap_Var =10 Short=0	92
Figure 151 LNAWA Sample=2 Gain=0, Cap_Var =10 Short=1	92
Figure 152 LNAWA Sample=2 Gain=0, Cap_Var =20 Short=0	93
Figure 153 LNAWA Sample=2 Gain=0, Cap_Var =20 Short=1	93
Figure 154 LNAWA Sample=2 Gain=0, Cap_Var =31 Short=0	94
Figure 155 LNAWA Sample=2 Gain=0, Cap_Var =31 Short=1	94
Figure 156 LNAWA Sample=2 Gain=6, Cap_Var =0 Short=0	95
Figure 157 LNAWA Sample=2 Gain=6, Cap_Var =10 Short=0	95
Figure 158 LNAWA Sample=2 Gain=6, Cap_Var =20 Short=0	96
Figure 159 LNAWA Sample=2 Gain=6, Cap_Var =31 Short=0	96
Figure 160 LNAWA Sample=2 Gain=18, Cap_Var =0 Short=0	97
Figure 161 LNAWA Sample=2 Gain=31, Cap_Var =0 Short=0	97
Figure 162 LNAWA Sample=3 Gain=0, Cap_Var=0 Short=0	98
Figure 163 LNAWA Sample=3 Gain=0, Cap_Var=0 Short=1	98
Figure 164 LNAWA Sample=3 Gain=0, Cap_Var =10 Short=0	99
Figure 165 LNAWA Sample=3 Gain=0, Cap_Var =10 Short=1	99
Figure 166 LNAWA Sample=3 Gain=0, Cap_Var =20 Short=0	100
Figure 167 LNAWA Sample=3 Gain=0, Cap_Var =20 Short=1	100
Figure 168 LNAWA Sample=3 Gain=0, Cap_Var =31 Short=0	101
Figure 169 LNAWA Sample=3 Gain=0, Cap_Var =31 Short=1	101
Figure 170 LNAWA Sample=3 Gain=6, Cap_Var =0 Short=0	102
Figure 171 LNAWA Sample=3 Gain=6, Cap_Var =10 Short=0	102
Figure 172 LNAWA Sample=3 Gain=6, Cap_Var =20 Short=0	103
Figure 173 LNAWA Sample=3 Gain=6, Cap_Var =31 Short=0	103
Figure 174 LNAWA Sample=3 Gain=18, Cap_Var =0 Short=0	104
Figure 175 LNAWA Sample=3 Gain=31, Cap_Var =0 Short=0	104
Figure 176 LNAWB Sample=1 Gain=0, Cap_Var=0 Short=0	105
Figure 177 LNAWB Sample=1 Gain=0, Cap_Var=0 Short=1	105
Figure 178 LNAWB Sample=1 Gain=0, Cap_Var =10 Short=0	106
Figure 179 LNAWB Sample=1 Gain=0, Cap_Var =10 Short=1	106
Figure 180 LNAWB Sample=1 Gain=0, Cap_Var =20 Short=0	107
Figure 181 LNAWB Sample=1 Gain=0, Cap_Var =20 Short=1	107
Figure 182 LNAWB Sample=1 Gain=0, Cap_Var =31 Short=0	108
Figure 183 LNAWB Sample=1 Gain=0, Cap_Var =31 Short=1	108
Figure 184 LNAWB Sample=1 Gain=6, Cap_Var =0 Short=0	109
Figure 185 LNAWB Sample=1 Gain=6, Cap_Var =10 Short=0	109
Figure 186 LNAWB Sample=1 Gain=6, Cap_Var =20 Short=0	110
Figure 187 LNAWB Sample=1 Gain=6, Cap_Var =31 Short=0	110
Figure 188 LNAWB Sample=1 Gain=18, Cap_Var =0 Short=0	111
Figure 189 LNAWB Sample=1 Gain=31, Cap_Var =0 Short=0	111
Figure 190 LNAWB Sample=2 Gain=0, Cap_Var=0 Short=0	112
Figure 191 LNAWB Sample=2 Gain=0, Cap_Var=0 Short=1	112
Figure 192 LNAWB Sample=2 Gain=0, Cap_Var =10 Short=0	113
Figure 193 LNAWB Sample=2 Gain=0, Cap_Var =10 Short=1	113
Figure 194 LNAWB Sample=2 Gain=0, Cap_Var =20 Short=0	114
Figure 195 LNAWB Sample=2 Gain=0, Cap_Var =20 Short=1	114
Figure 196 LNAWB Sample=2 Gain=0, Cap_Var =31 Short=0	115
Figure 197 LNAWB Sample=2 Gain=0, Cap_Var =31 Short=1	115

Figure 198 LNAWB Sample=2 Gain=6, Cap_Var =0 Short=0	116
Figure 199 LNAWB Sample=2 Gain=6, Cap_Var =10 Short=0	116
Figure 200 LNAWB Sample=2 Gain=6, Cap_Var =20 Short=0	117
Figure 201 LNAWB Sample=2 Gain=6, Cap_Var =31 Short=0	117
Figure 202 LNAWB Sample=2 Gain=18, Cap_Var =0 Short=0	118
Figure 203 LNAWB Sample=2 Gain=31, Cap_Var =0 Short=0	118
Figure 204 LNAWB Sample=3 Gain=0, Cap_Var=0 Short=0	119
Figure 205 LNAWB Sample=3 Gain=0, Cap_Var=0 Short=1	119
Figure 206 LNAWB Sample=3 Gain=0, Cap_Var =10 Short=0	120
Figure 207 LNAWB Sample=3 Gain=0, Cap_Var =10 Short=1	120
Figure 208 LNAWB Sample=3 Gain=0, Cap_Var =20 Short=0	121
Figure 209 LNAWB Sample=3 Gain=0, Cap_Var =20 Short=1	121
Figure 210 LNAWB Sample=3 Gain=0, Cap_Var =31 Short=0	122
Figure 211 LNAWB Sample=3 Gain=0, Cap_Var =31 Short=1	122
Figure 212 LNAWB Sample=3 Gain=6, Cap_Var =0 Short=0	123
Figure 213 LNAWB Sample=3 Gain=6, Cap_Var =10 Short=0	123
Figure 214 LNAWB Sample=3 Gain=6, Cap_Var =20 Short=0	124
Figure 215 LNAWB Sample=3 Gain=6, Cap_Var =31 Short=0	124
Figure 216 LNAWB Sample=3 Gain=18, Cap_Var =0 Short=0	125
Figure 217 LNAWB Sample=3 Gain=31, Cap_Var =0 Short=0	125

Revision History

Version 01r00

Started: 24th April, 2015

Finished: 15th May 2015

Initial version.

Version 1.1

Started 15th June 2015

Finished 17th June 2015

Added graphs of s-parameter files.

1 Introduction

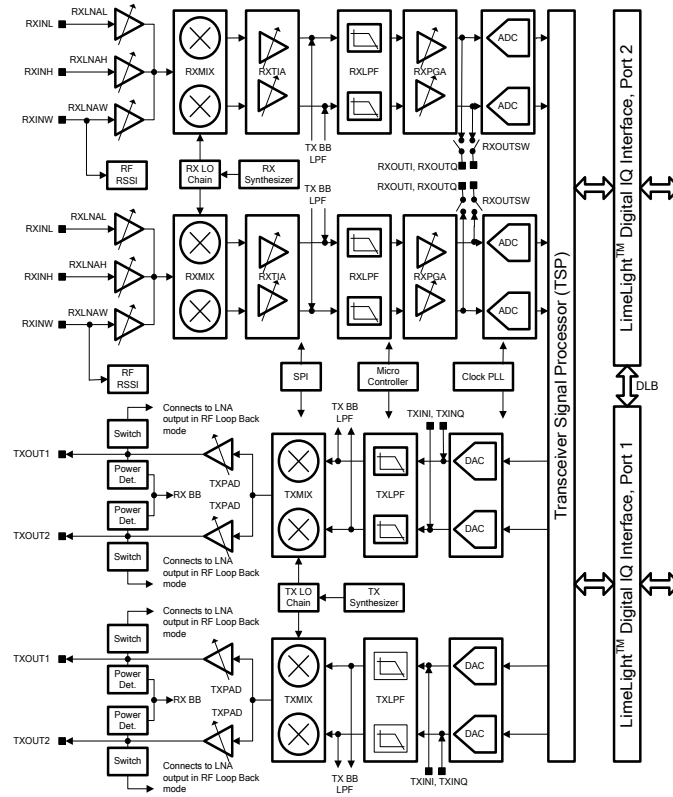


Figure 1 LMS7002M Architecture

The LMS7002M is a field programmable software defined radio transceiver integrated circuit radio system covering the frequency range from 100kHz to 3800MHz. A block diagram of the transceiver is shown in *Figure 1*. The transceiver consists of two MIMO channels each with 3 LNA inputs and 2 TX outputs, ADC/DAC, synthesizers and signal processing.

This report focuses on the characterisation of the six LNA inputs.

1.1 Principles of S-parameter Measurements

Scattering parameters (s-parameters) are used to characterize various microwave devices in the frequency domain. Measurements of transmission and reflection are made on the device under test. S-parameters are usually measured with a Vector Network Analyzer (VNA) which measures both magnitude and phase. (Scalar Network Analyzers only measure magnitude). Most VNAs measure only 2-ports. All VNAs require calibration before accurate measurements can be made. The most commonly used calibration kits are Short, Open, Load, Through (SOLT) and the Line, Reflect, Match (LRM). The calibration kit calibrates to “the reference plane” of the measurements. For a SOLT calibration, the reference plane is the external interface surface of the connectors.

Generally s-parameter measurements are made on a test board or fixture and the measurements have to be post processed to remove the effects of the test fixture connections on the measurements. This process is commonly called de-embedding.

De-embedding is generally carried out in a circuit simulator environment. The components to be removed are entered as negative line lengths or negative component values. The components being de-embedded closest to the reference plane are de-embedded first from the measured s-parameter file. The components being de-embedded closest to the device being characterized are closest to the simulation port.

Measured s-parameters can be affected by the amplitude of the sweep from the VNA. Too low and the measurements will be noisy. Too high, and semiconductor devices will deviate from their small signal behavior. Typically -20dBm or -30dBm VNA output power is advisable for s-parameter measurements of the LMS7002.

2 Design of the Lime Characterization Boards

Lime has used the following principles to minimize errors in the de-embedding process:

- (i) Use of Rogers 4350 for the microstrip environment and FR4 for noncritical layers.
- (ii) Track thickness of the test fixture are kept reasonably wide to give a well-defined electrical length and characteristic impedance. Bends are only 45 degrees to remove the need of chamfered bends.
- (iii) Physical lengths of lines kept short as possible.
- (iv) Only very short lengths of lines of minimum thickness and space are used.
- (v) The number of passive devices included in the test fixture RF path are kept to a minimum with values which have the least effect over the frequency range of the measurements.
- (vi) Calibration structures to model SMA connectors.

The some of the characterization boards used are shown in *Figure 2*.



Figure 2 S-parameter Characterisation Boards.

2.1 S-parameter Files

S-parameters were measured with an Agilent (Keysight) E5071C using an 8509X e-cal module and then de-embedded. The de-embedded s-parameter files are in LMS7002M_LNA_sparams.zip. The zip file contains measurements for 2-3 samples of each of the 6 LNAs. They are stored in the directories shown in **Table 1**. Where A and B denote MIMO channels A and B. H, L and W denote high band, low band, and wideband LNAs. The files in each directory are listed in **Table 2**, **Table 3** and **Table 4**.

Files were measured for different gains and different programmable input capacitor settings (Cap_Var). LNAW and LNAL also have a programmable input short circuit switch and this is also measured. The LNA gain is always relative to maximum gain. Absolute gain is frequency dependent.

Each s-parameter file is a 2-port file with each port corresponding to one of the two inputs of the differential LNA. The reference plane of the de-embedded s-parameters is the package pin. PCB pads have been de-embedded.

Table 1 List of Directories in LMS7002M_LNA_sparams.zip

LNAHA_3A1	LNALA_2A1	LNAWA_1A1
LNAHA_3A2	LNALA_2A2	LNAWA_1A2
LNAHA_3A3	LNALA_2A3	LNAWA_1A3
LNAHB_3B2	LNALB_2B1	LNAWB_1B1
LNAHB_3B3	LNALB_2B2	LNAWB_1B2
	LNALB_2B3	LNAWB_1B3

Table 2 List of Files in the LNAH Directories

LNAHA_3A1	Gain	Cap_Var	LNAHB_3B2	Gain	Cap_Var
LNAHA_G0_CV0.s2p	0	0	LNAHB_G0_CV0.s2p	0	0
LNAHA_G0_CV10.s2p	0	10	LNAHB_G0_CV10.s2p	0	10
LNAHA_G0_CV20.s2p	0	20	LNAHB_G0_CV20.s2p	0	20
LNAHA_G0_CV31.s2p	0	31	LNAHB_G0_CV31.s2p	0	31
LNAHA_G6_CV0.s2p	-6	0	LNAHB_G6_CV0.s2p	-6	0
LNAHA_G6_CV10.s2p	-6	10	LNAHB_G6_CV10.s2p	-6	10
LNAHA_G6_CV20.s2p	-6	20	LNAHB_G6_CV20.s2p	-6	20
LNAHA_G6_CV31.s2p	-6	31	LNAHB_G6_CV31.s2p	-6	31
LNAHA_G18_CV0.s2p	-18	0	LNAHB_G18_CV0.s2p	-18	0
LNAHA_G30_CV0.s2p	-30	0	LNAHB_G30_CV0.s2p	-30	0
LNAHA_3A2	Gain	Cap_Var	LNAHB_3B3	Gain	Cap_Var
LNAHA_G0_CV0.s2p	0	0	LNAHB_G0_CV0.s2p	0	0
LNAHA_G0_CV10.s2p	0	10	LNAHB_G0_CV10.s2p	0	10
LNAHA_G0_CV20.s2p	0	20	LNAHB_G0_CV20.s2p	0	20
LNAHA_G0_CV31.s2p	0	31	LNAHB_G0_CV31.s2p	0	31
LNAHA_G6_CV0.s2p	-6	0	LNAHB_G6_CV0.s2p	-6	0
LNAHA_G6_CV10.s2p	-6	10	LNAHB_G6_CV10.s2p	-6	10
LNAHA_G6_CV20.s2p	-6	20	LNAHB_G6_CV20.s2p	-6	20
LNAHA_G6_CV31.s2p	-6	31	LNAHB_G6_CV31.s2p	-6	31
LNAHA_G18_CV0.s2p	-18	0	LNAHB_G18_CV0.s2p	-18	0
LNAHA_G30_CV0.s2p	-30	0	LNAHB_G30_CV0.s2p	-30	0
LNAHA_3A3	Gain	Cap_Var			
LNAHA_G0_CV0.s2p	0	0			
LNAHA_G0_CV10.s2p	0	10			
LNAHA_G0_CV20.s2p	0	20			
LNAHA_G0_CV31.s2p	0	31			
LNAHA_G6_CV0.s2p	-6	0			
LNAHA_G6_CV10.s2p	-6	10			
LNAHA_G6_CV20.s2p	-6	20			
LNAHA_G6_CV31.s2p	-6	31			
LNAHA_G18_CV0.s2p	-18	0			
LNAHA_G30_CV0.s2p	-30	0			

Table 3 List of Files in the LNAL Directories

LNALA_2A1	Gain	Cap_Var	Short		LNALB_2B1	Gain	Cap_Var	Short
LNALA_G0_CV0.s2p	0	0	off		LNALB_G0_CV0.s2p	0	0	off
LNALA_G0_CV10.s2p	0	10	off		LNALB_G0_CV10.s2p	0	10	off
LNALA_G0_CV20.s2p	0	20	off		LNALB_G0_CV20.s2p	0	20	off
LNALA_G0_CV31.s2p	0	31	off		LNALB_G0_CV31.s2p	0	31	off
LNALA_G0_CV0_SH.s2p	0	0	on		LNALB_G0_CV0_SH.s2p	0	0	on
LNALA_G0_CV10_SH.s2p	0	10	on		LNALB_G0_CV10_SH.s2p	0	10	on
LNALA_G0_CV20_SH.s2p	0	20	on		LNALB_G0_CV20_SH.s2p	0	20	on
LNALA_G0_CV31_SH.s2p	0	31	on		LNALB_G0_CV31_SH.s2p	0	31	on
LNALA_G6_CV0.s2p	-6	0	off		LNALB_G6_CV0.s2p	-6	0	off
LNALA_G6_CV10.s2p	-6	10	off		LNALB_G6_CV10.s2p	-6	10	off
LNALA_G6_CV20.s2p	-6	20	off		LNALB_G6_CV20.s2p	-6	20	off
LNALA_G6_CV31.s2p	-6	31	off		LNALB_G6_CV31.s2p	-6	31	off
LNALA_G18_CV0.s2p	-18	0	off		LNALB_G18_CV0.s2p	-18	0	off
LNALA_G30_CV0.s2p	-30	0	off		LNALB_G30_CV0.s2p	-30	0	off
LNALA_2A2	Gain	Cap_Var	Short		LNALB_2B2	Gain	Cap_Var	Short
LNALA_G0_CV0.s2p	0	0	off		LNALB_G0_CV0.s2p	0	0	off
LNALA_G0_CV10.s2p	0	10	off		LNALB_G0_CV10.s2p	0	10	off
LNALA_G0_CV20.s2p	0	20	off		LNALB_G0_CV20.s2p	0	20	off
LNALA_G0_CV31.s2p	0	31	off		LNALB_G0_CV31.s2p	0	31	off
LNALA_G0_CV0_SH.s2p	0	0	on		LNALB_G0_CV0_SH.s2p	0	0	on
LNALA_G0_CV10_SH.s2p	0	10	on		LNALB_G0_CV10_SH.s2p	0	10	on
LNALA_G0_CV20_SH.s2p	0	20	on		LNALB_G0_CV20_SH.s2p	0	20	on
LNALA_G0_CV31_SH.s2p	0	31	on		LNALB_G0_CV31_SH.s2p	0	31	on
LNALA_G6_CV0.s2p	-6	0	off		LNALB_G6_CV0.s2p	-6	0	off
LNALA_G6_CV10.s2p	-6	10	off		LNALB_G6_CV10.s2p	-6	10	off
LNALA_G6_CV20.s2p	-6	20	off		LNALB_G6_CV20.s2p	-6	20	off
LNALA_G6_CV31.s2p	-6	31	off		LNALB_G6_CV31.s2p	-6	31	off
LNALA_G18_CV0.s2p	-18	0	off		LNALB_G18_CV0.s2p	-18	0	off
LNALA_G30_CV0.s2p	-30	0	off		LNALB_G30_CV0.s2p	-30	0	off
LNALA_2A3	Gain	Cap_Var	Short		LNALB_2B3	Gain	Cap_Var	Short
LNALA_G0_CV0.s2p	0	0	off		LNALB_G0_CV0.s2p	0	0	off
LNALA_G0_CV10.s2p	0	10	off		LNALB_G0_CV10.s2p	0	10	off
LNALA_G0_CV20.s2p	0	20	off		LNALB_G0_CV20.s2p	0	20	off
LNALA_G0_CV31.s2p	0	31	off		LNALB_G0_CV31.s2p	0	31	off
LNALA_G0_CV0_SH.s2p	0	0	on		LNALB_G0_CV0_SH.s2p	0	0	on
LNALA_G6_CV0.s2p	-6	0	off		LNALB_G0_CV10_SH.s2p	0	10	on
LNALA_G6_CV10.s2p	-6	10	off		LNALB_G0_CV20_SH.s2p	0	20	on
LNALA_G6_CV20.s2p	-6	20	off		LNALB_G0_CV31_SH.s2p	0	31	on
LNALA_G6_CV31.s2p	-6	31	off		LNALB_G6_CV0.s2p	-6	0	off
LNALA_G18_CV0.s2p	-18	0	off		LNALB_G6_CV10.s2p	-6	10	off
LNALA_G30_CV0.s2p	-30	0	off		LNALB_G6_CV20.s2p	-6	20	off
					LNALB_G6_CV31.s2p	-6	31	off
					LNALB_G18_CV0.s2p	-18	0	off
					LNALB_G30_CV0.s2p	-30	0	off

Table 4 List of Files in the LNAW Directories

LNAWA_2A1	Gain	Cap_Var	Short	LNAWB_2B1	Gain	Cap_Var	Short
LNAWA_G0_CV0.s2p	0	0	off	LNAWB_G0_CV0.s2p	0	0	off
LNAWA_G0_CV10.s2p	0	10	off	LNAWB_G0_CV10.s2p	0	10	off
LNAWA_G0_CV20.s2p	0	20	off	LNAWB_G0_CV20.s2p	0	20	off
LNAWA_G0_CV31.s2p	0	31	off	LNAWB_G0_CV31.s2p	0	31	off
LNAWA_G0_CV0_SH.s2p	0	0	on	LNAWB_G0_CV0_SH.s2p	0	0	on
LNAWA_G0_CV10_SH.s2p	0	10	on	LNAWB_G0_CV10_SH.s2p	0	10	on
LNAWA_G0_CV20_SH.s2p	0	20	on	LNAWB_G0_CV20_SH.s2p	0	20	on
LNAWA_G0_CV31_SH.s2p	0	31	on	LNAWB_G0_CV31_SH.s2p	0	31	on
LNAWA_G6_CV0.s2p	-6	0	off	LNAWB_G6_CV0.s2p	-6	0	off
LNAWA_G18_CV0.s2p	-18	0	off	LNAWB_G6_CV10.s2p	-6	10	off
LNAWA_G30_CV0.s2p	-30	0	off	LNAWB_G6_CV20.s2p	-6	20	off
				LNAWB_G6_CV31.s2p	-6	31	off
				LNAWB_G18_CV0.s2p	-18	0	off
				LNAWB_G30_CV0.s2p	-30	0	off
LNAWA_2A2	Gain	Cap_Var	Short	LNAWB_2B2	Gain	Cap_Var	Short
LNAWA_G0_CV0.s2p	0	0	off	LNAWB_G0_CV0.s2p	0	0	off
LNAWA_G0_CV10.s2p	0	10	off	LNAWB_G0_CV10.s2p	0	10	off
LNAWA_G0_CV20.s2p	0	20	off	LNAWB_G0_CV20.s2p	0	20	off
LNAWA_G0_CV31.s2p	0	31	off	LNAWB_G0_CV31.s2p	0	31	off
LNAWA_G0_CV0_SH.s2p	0	0	on	LNAWB_G0_CV0_SH.s2p	0	0	on
LNAWA_G0_CV10_SH.s2p	0	10	on	LNAWB_G0_CV10_SH.s2p	0	10	on
LNAWA_G0_CV20_SH.s2p	0	20	on	LNAWB_G0_CV20_SH.s2p	0	20	on
LNAWA_G0_CV31_SH.s2p	0	31	on	LNAWB_G0_CV31_SH.s2p	0	31	on
LNAWA_G6_CV0.s2p	-6	0	off	LNAWB_G6_CV0.s2p	-6	0	off
LNAWA_G6_CV10.s2p	-6	10	off	LNAWB_G6_CV10.s2p	-6	10	off
LNAWA_G6_CV20.s2p	-6	20	off	LNAWB_G6_CV20.s2p	-6	20	off
LNAWA_G6_CV31.s2p	-6	31	off	LNAWB_G6_CV31.s2p	-6	31	off
LNAWA_G18_CV0.s2p	-18	0	off	LNAWB_G18_CV0.s2p	-18	0	off
LNAWA_G30_CV0.s2p	-30	0	off	LNAWB_G30_CV0.s2p	-30	0	off
LNAWA_2A3	Gain	Cap_Var	Short	LNAWB_2B3	Gain	Cap_Var	Short
LNAWA_G0_CV0.s2p	0	0	off	LNAWB_G0_CV0.s2p	0	0	off
LNAWA_G0_CV10.s2p	0	10	off	LNAWB_G0_CV10.s2p	0	10	off
LNAWA_G0_CV20.s2p	0	20	off	LNAWB_G0_CV20.s2p	0	20	off
LNAWA_G0_CV31.s2p	0	31	off	LNAWB_G0_CV31.s2p	0	31	off
LNAWA_G0_CV0_SH.s2p	0	0	on	LNAWB_G0_CV0_SH.s2p	0	0	on
LNAWA_G0_CV10_SH.s2p	0	10	on	LNAWB_G0_CV10_SH.s2p	0	10	on
LNAWA_G0_CV20_SH.s2p	0	20	on	LNAWB_G0_CV20_SH.s2p	0	20	on
LNAWA_G0_CV31_SH.s2p	0	31	on	LNAWB_G0_CV31_SH.s2p	0	31	on
LNAWA_G6_CV0.s2p	-6	0	off	LNAWB_G6_CV0.s2p	-6	0	off
LNAWA_G6_CV10.s2p	-6	10	off	LNAWB_G6_CV10.s2p	-6	10	off
LNAWA_G6_CV20.s2p	-6	20	off	LNAWB_G6_CV20.s2p	-6	20	off
LNAWA_G6_CV31.s2p	-6	31	off	LNAWB_G6_CV31.s2p	-6	31	off
LNAWA_G18_CV0.s2p	-18	0	off	LNAWB_G18_CV0.s2p	-18	0	off
LNAWA_G30_CV0.s2p	-30	0	off	LNAWB_G30_CV0.s2p	-30	0	off

3 Example Simulation

In this chapter the LMS7002M evaluation board S-parameters are measured and compared with simulated results.

3.1 Simulation of the LMS7002M Evaluation Board LNAWA input.

A schematic was generated of the LNAWA part of the LMS7002M evaluation board using the default RF matching component values. The s-parameters of the LNAWA characterization was used to represent the impedance of the LNA. Manufacturer's S-parameter files were used to describe the transformer balun, capacitors and inductor in the matching network.

A comparison of the measured and simulated results are shown in *Figure 3* for max LNA gain and minimum programmable input capacitance (set to 0). It can be seen that the s-parameter simulations were accurate to about 2.5GHz, but above this frequency the simulation becomes progressively more sensitive to sample to sample variation of both passive and active components.

The effect of LNA gain on match is shown in *Figure 4*, and it can be seen clearly that the LNA gain has almost no effect on matching.

The effect of the LNA programmable input capacitor is shown in *Figure 5*. This programmable input capacitor provides a convenient method to adjust a matching network for component tolerances without the need to change physical components.

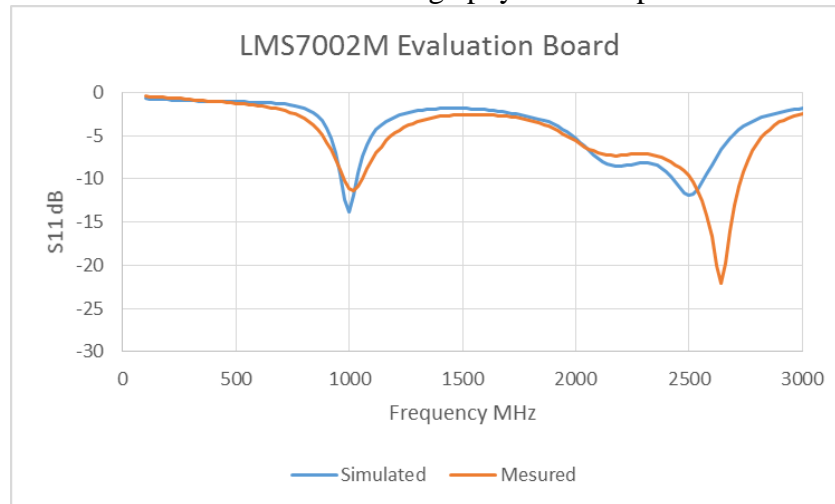


Figure 3 Simulated and Measured S_{11} of LMS7002M LNAWA.

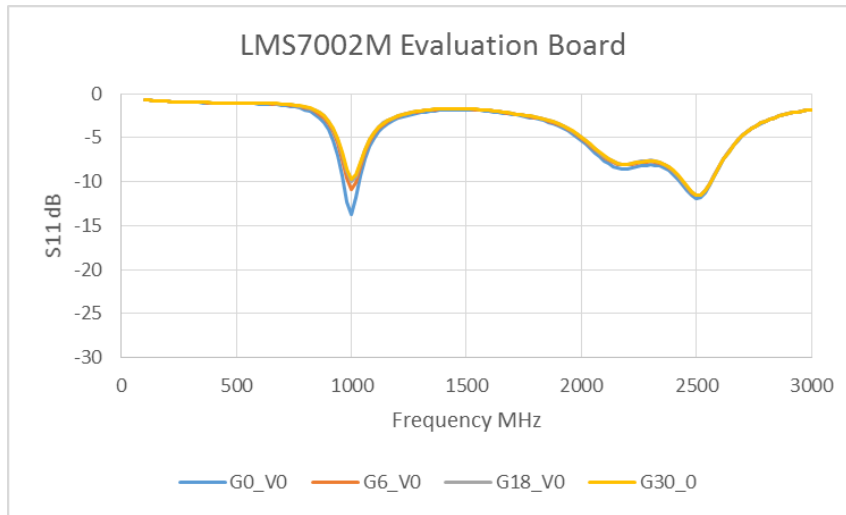


Figure 4 Simulated variation of S_{11} of LMS7002M LNALA with LNA gain.

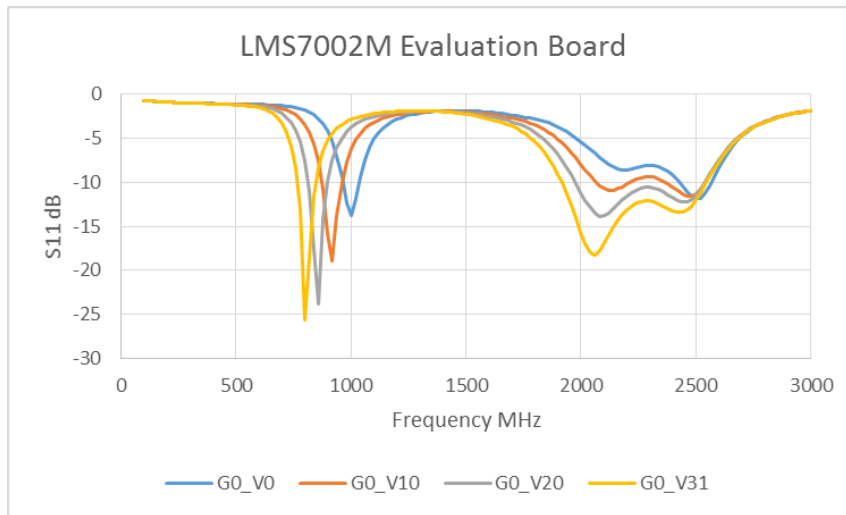


Figure 5 Simulated variation of S_{11} of LMS7002M LNALA with input capacitance code.

3.2 Common difficulties with simulating with S-parameters

When simulating with s-parameters, a number of difficulties can affect the agreement between measured and simulated s-parameters.

Not all manufacturers provide s-parameter data or equivalent circuit models for their components. Sometimes s-parameters are provided, but the frequency range may be unsuitable, or the reference plane poorly defined or the measurements not fully de-embedded.

Many ordinary devices, such as capacitors and inductors, have losses which are frequency and dielectric dependent, which cannot be easily modelled as a simple lumped element equivalent. Such components are essential for bias and DC blocking of active devices.

Passive devices such as surface mount capacitors are made by a variety of manufacturers to the same value, but may have significant differences in parasitics.

Some devices may have significant sample to sample variation, such as wound transformers and small value capacitors.

Many common PCB tools draw tracks as lines of different thicknesses with rounded ends and these do not readily convert into common microwave library parts.

PCB substrate materials are compressed together to make a multilayer boards, the resultant thicknesses of individual layers will have some tolerance. FR4 has a dielectric constant that often varies with distance due to the grouping of glass fibers in the weave, it is also sensitive to atmospheric moisture. Etching of small tracks needed for modern miniature devices also leads to uncertainty of track thicknesses and spaces. Most PCBs are covered with a layer of solder resist (often of unspecified thickness with unspecified dielectric properties) and this significantly affects coupling of closely spaced tracks.

3.3 S-parameters and TX Output

S-parameters for the TX outputs have not been provided. This is because the TX outputs are essentially current sources and best performance is obtained through a “load pull” approach rather than conjugate matching. Load pull is the method of choice for power amplifier optimization. For low frequencies <2.5GHz, no matching is generally needed for the LMS7002M TX outputs when loaded with 50R and RF components are placed close to the device.

The Maury 1819B triple stub tuner is very useful for “quick” load pull measurements over 800-4000MHz. Normally for best OIP3 performance at maximum output power the tuner has to be tuned a dB or so away from maximum output power.

4 Measured S-parameter Graphs

We show graphs of the de-embedded measurements for several samples of each LNA for different operating conditions in *Figure 6* to *Figure 217*. S11 and S22 correspond to the two differential inputs of each LNA.

4.1 LNAH channel A sample 1

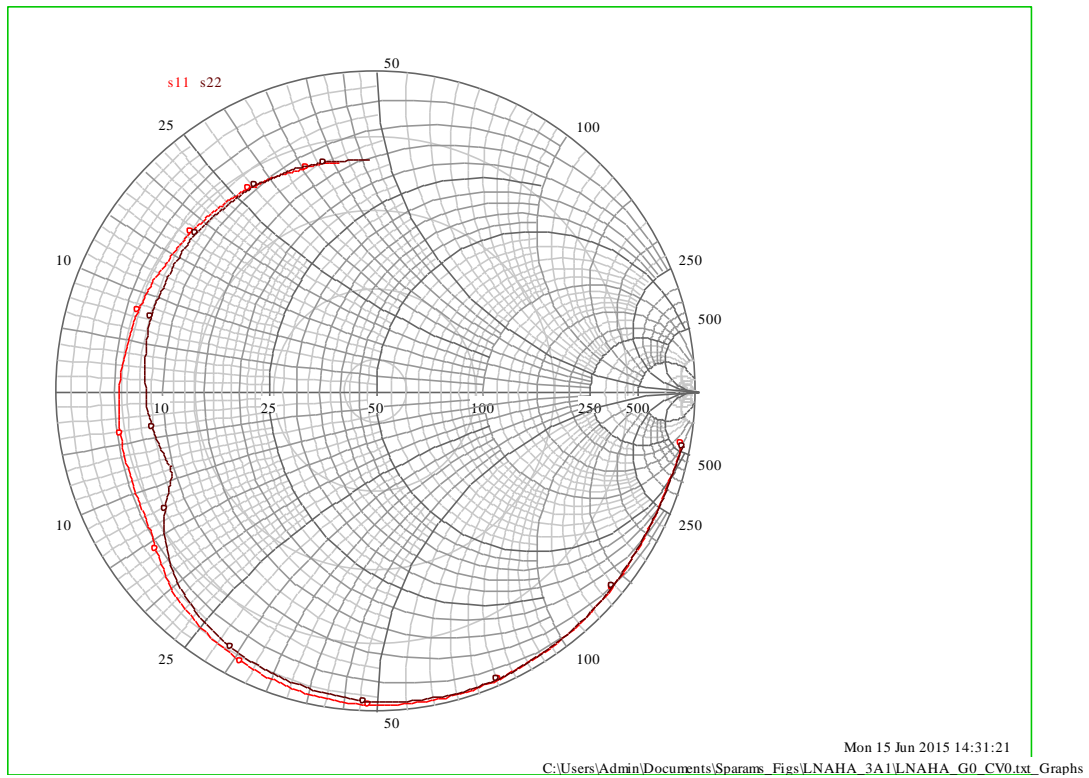


Figure 6 LNAHA Sample=1 Gain=0, Cap_Var=0

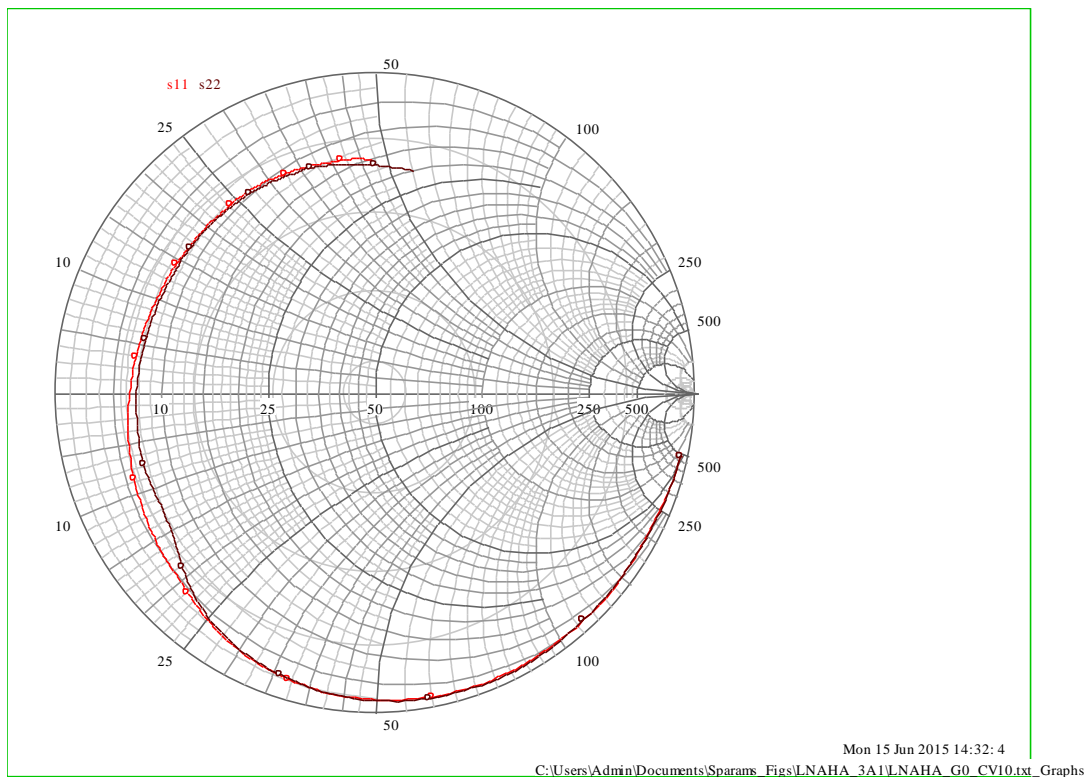


Figure 7 LNAHA Sample=1 Gain=0, Cap_Var =10

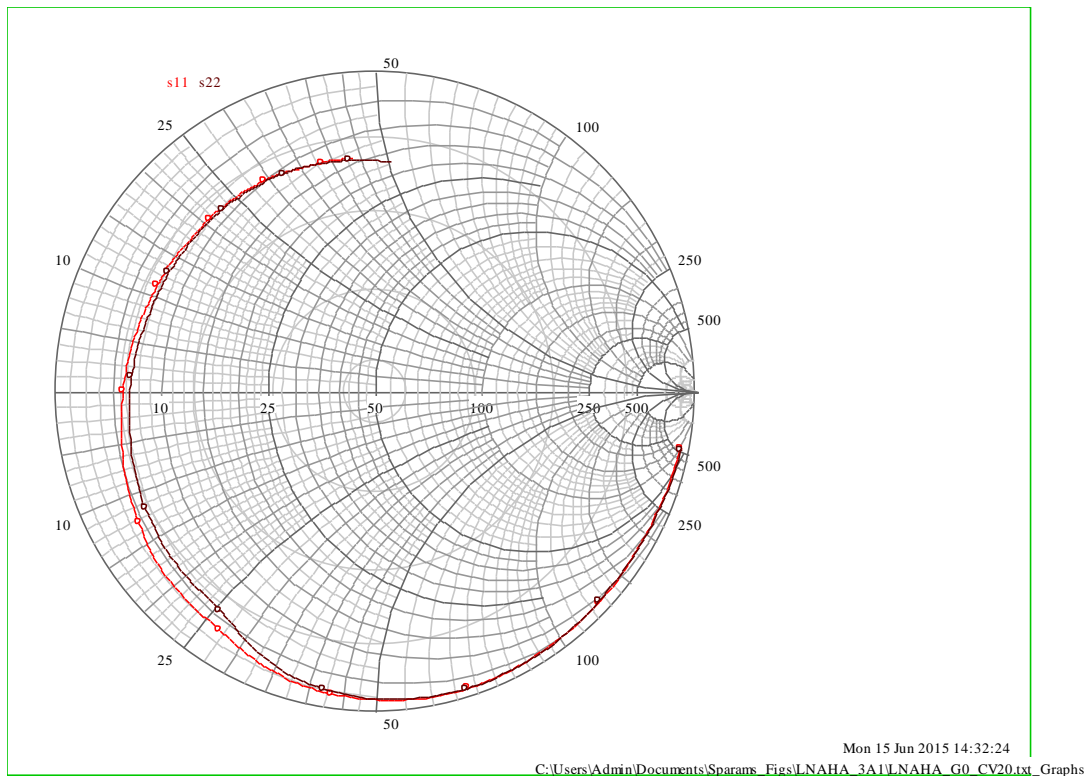


Figure 8 LNAHA Sample=1 Gain=0, Cap_Var =20

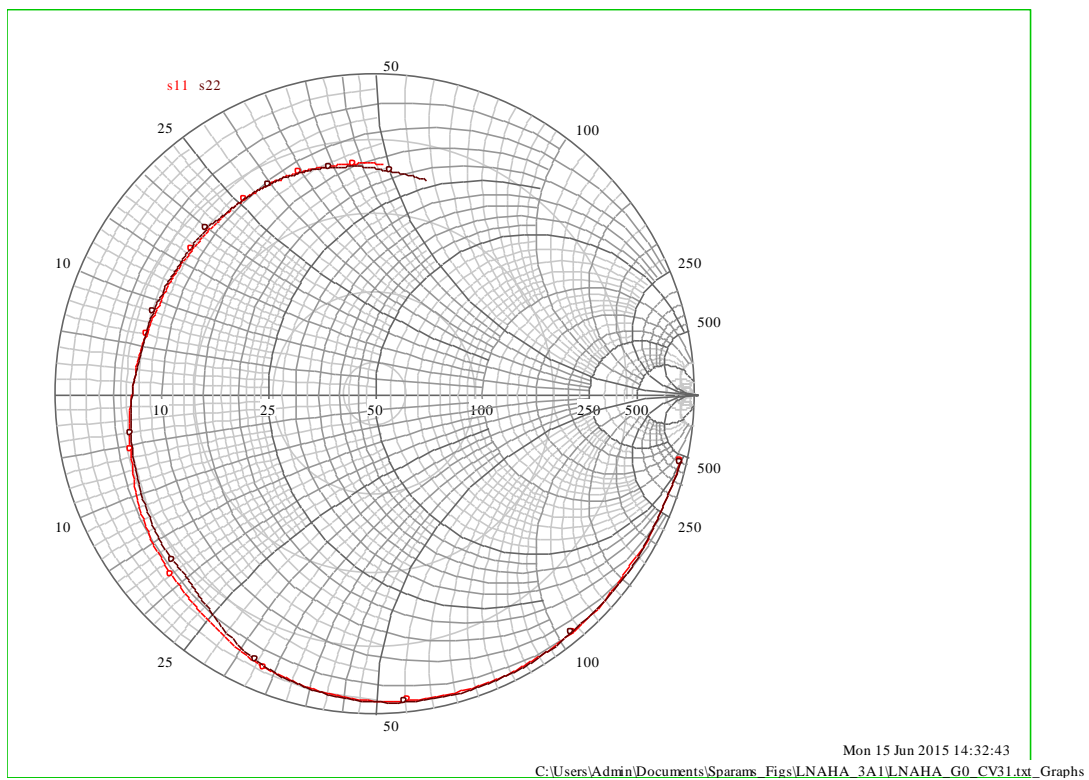


Figure 9 LNAHA Sample=1 Gain=0, Cap_Var =31

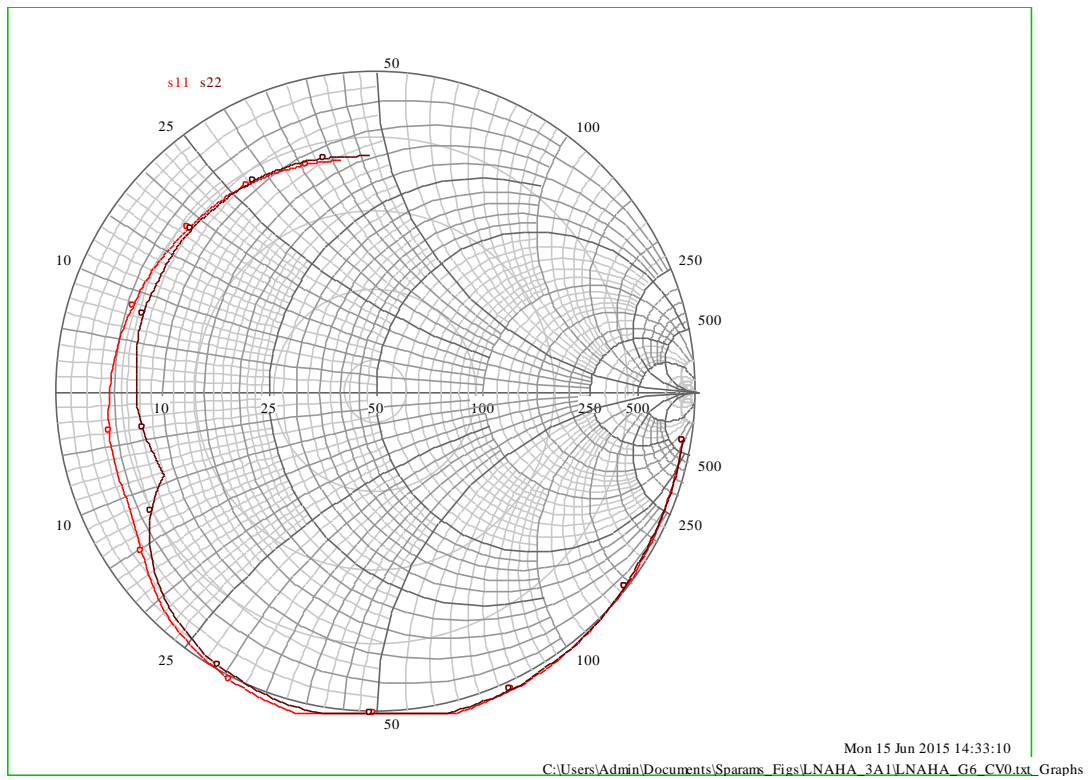


Figure 10 LNAHA Sample=1 Gain=6, Cap_Var =0

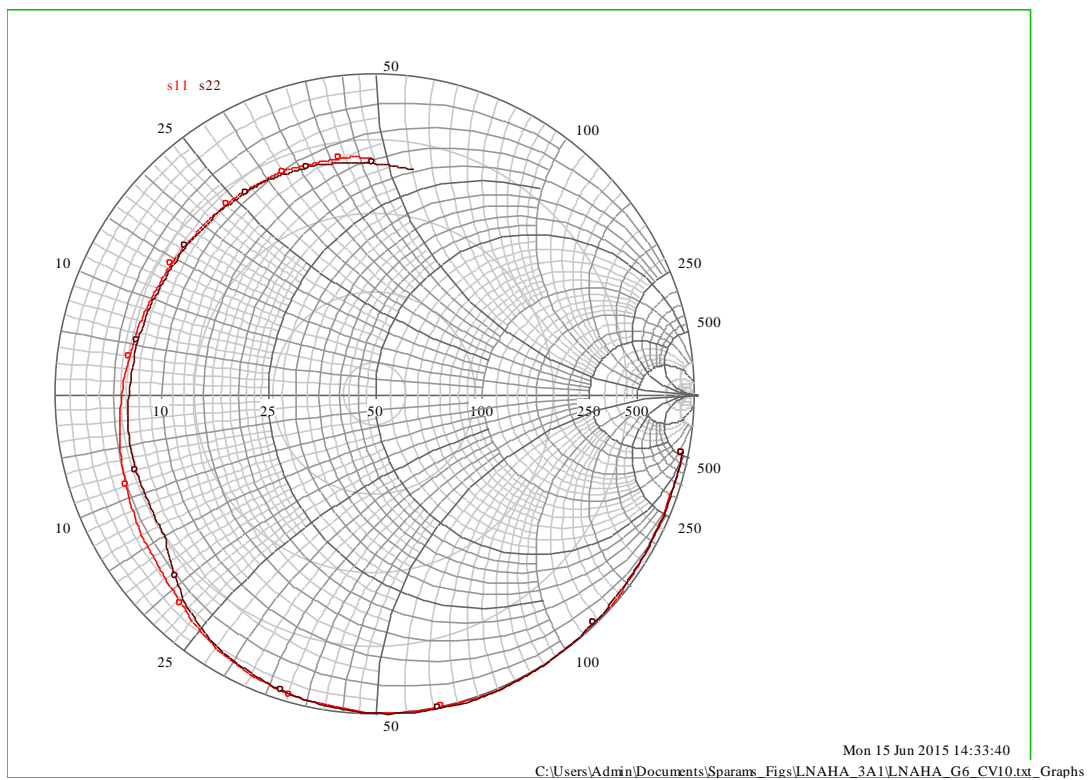


Figure 11 LNAHA Sample=1 Gain=6, Cap_Var =10

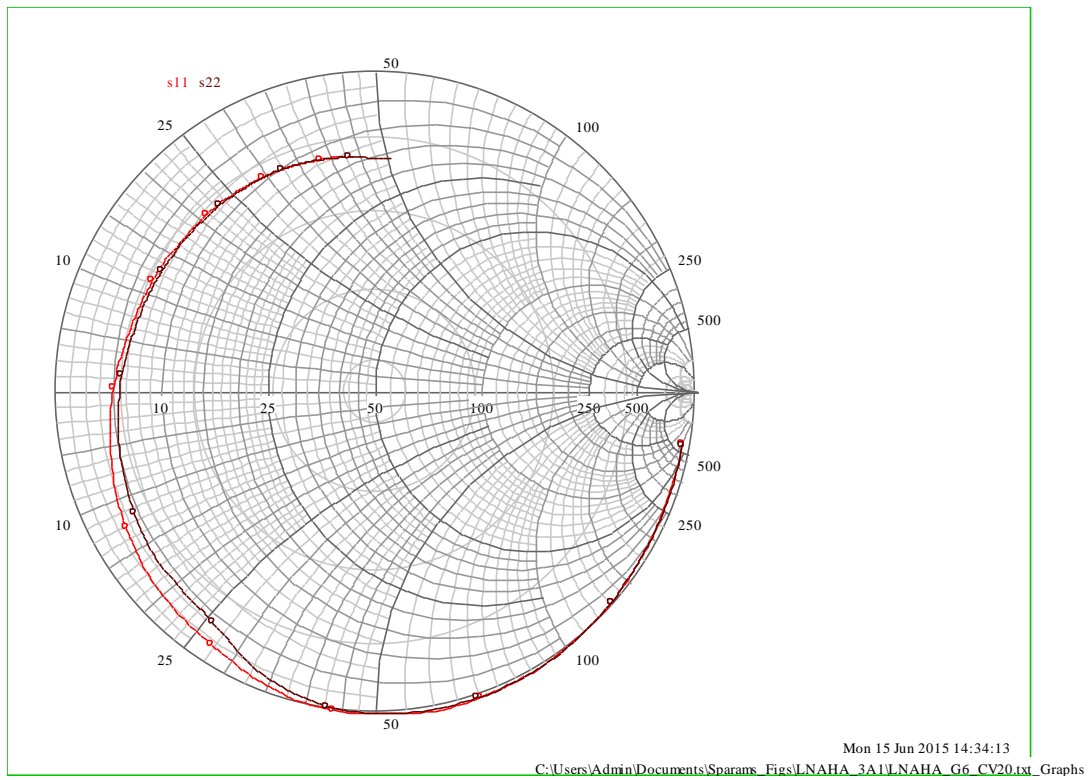


Figure 12 LNAHA Sample=1 Gain=6, Cap_Var =20

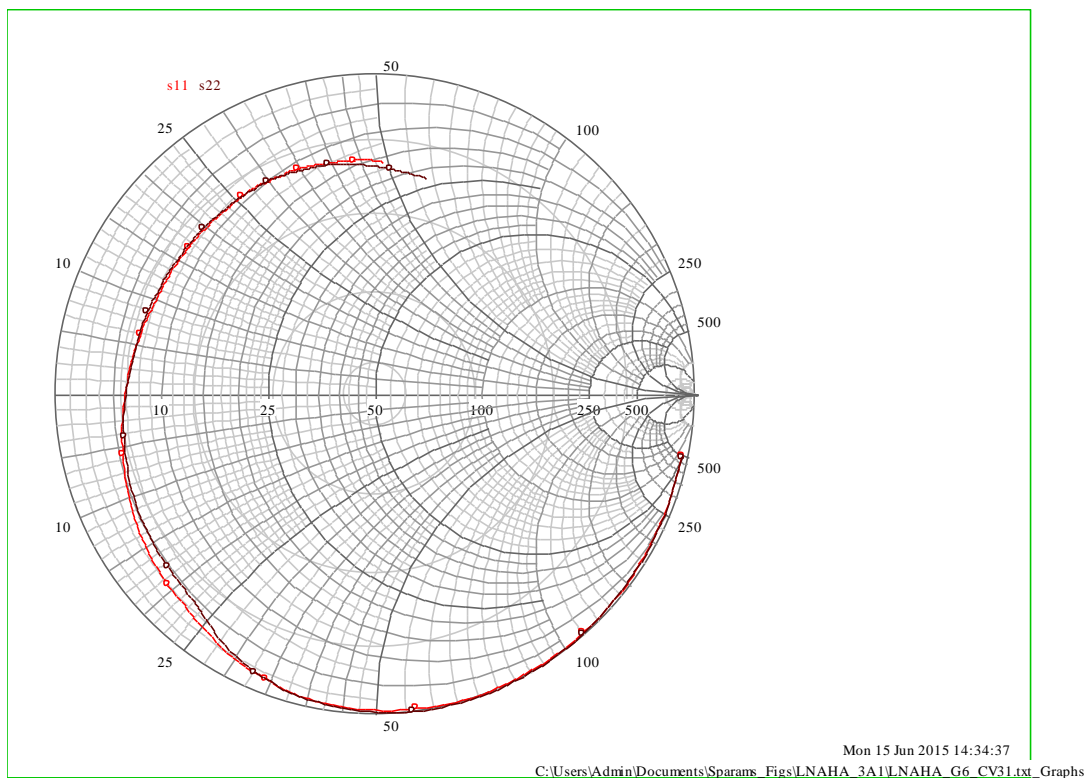


Figure 13 LNAHA Sample=1 Gain=6, Cap_Var =31

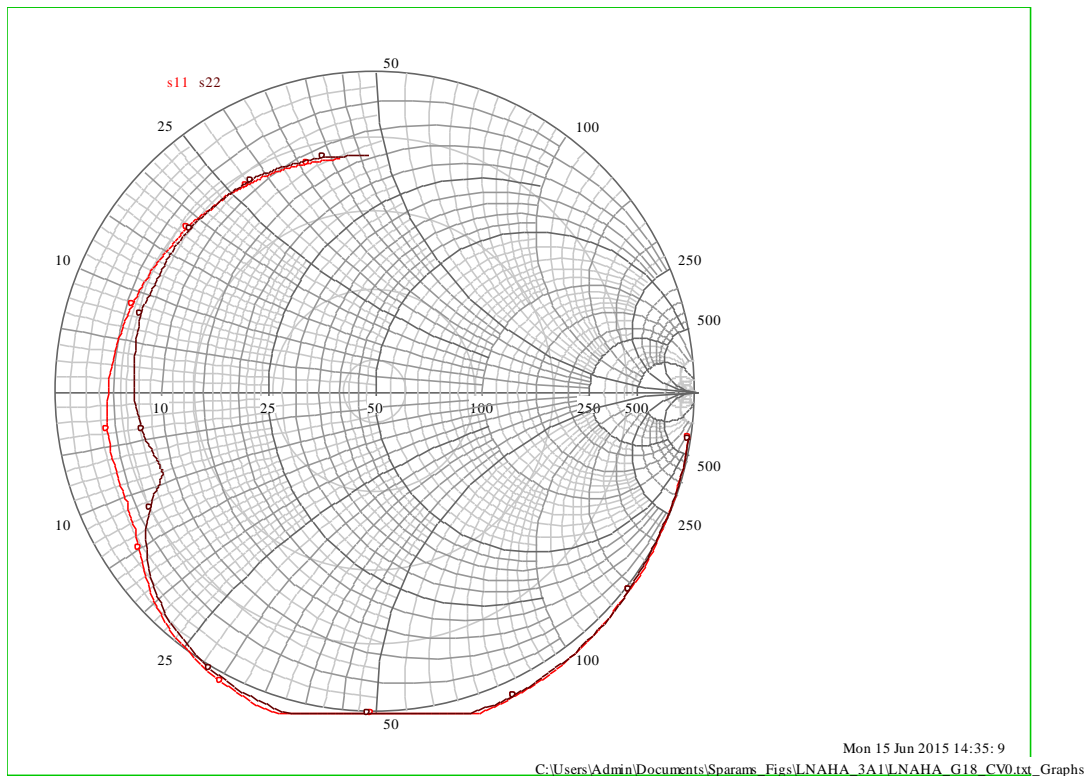


Figure 14 LNAHA Sample=1 Gain=18, Cap_Var =0

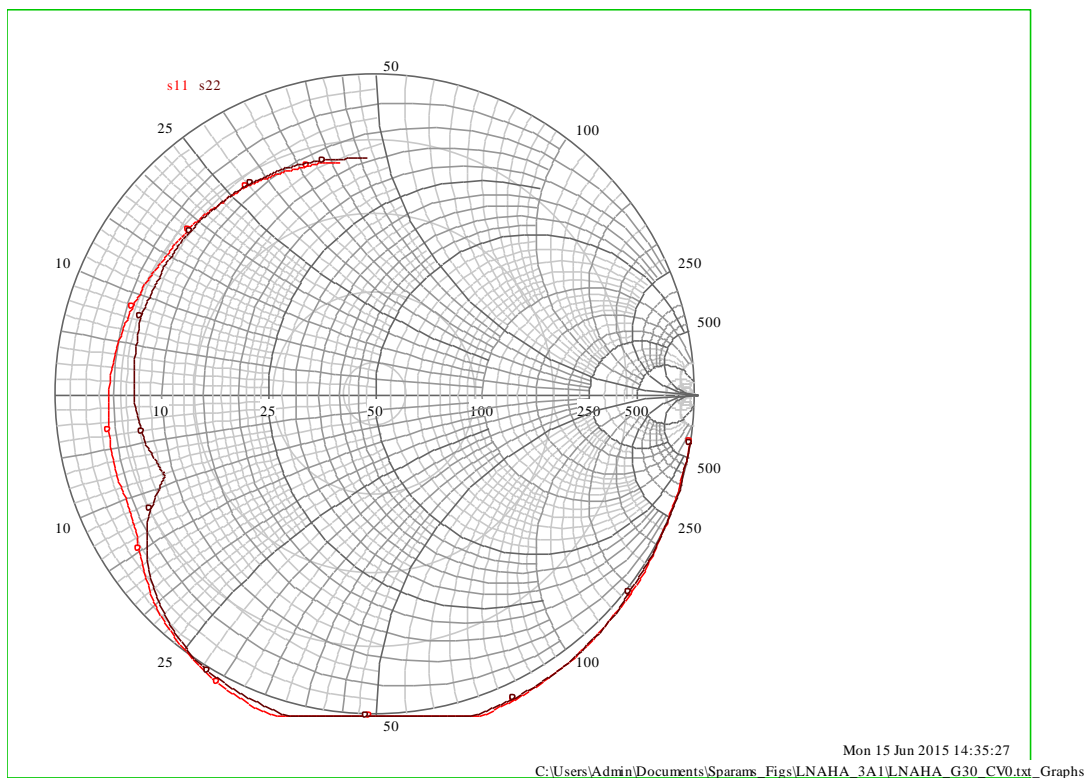


Figure 15 LNAHA Sample=1 Gain=31, Cap_Var =0

4.2 LNAH channel A sample 2

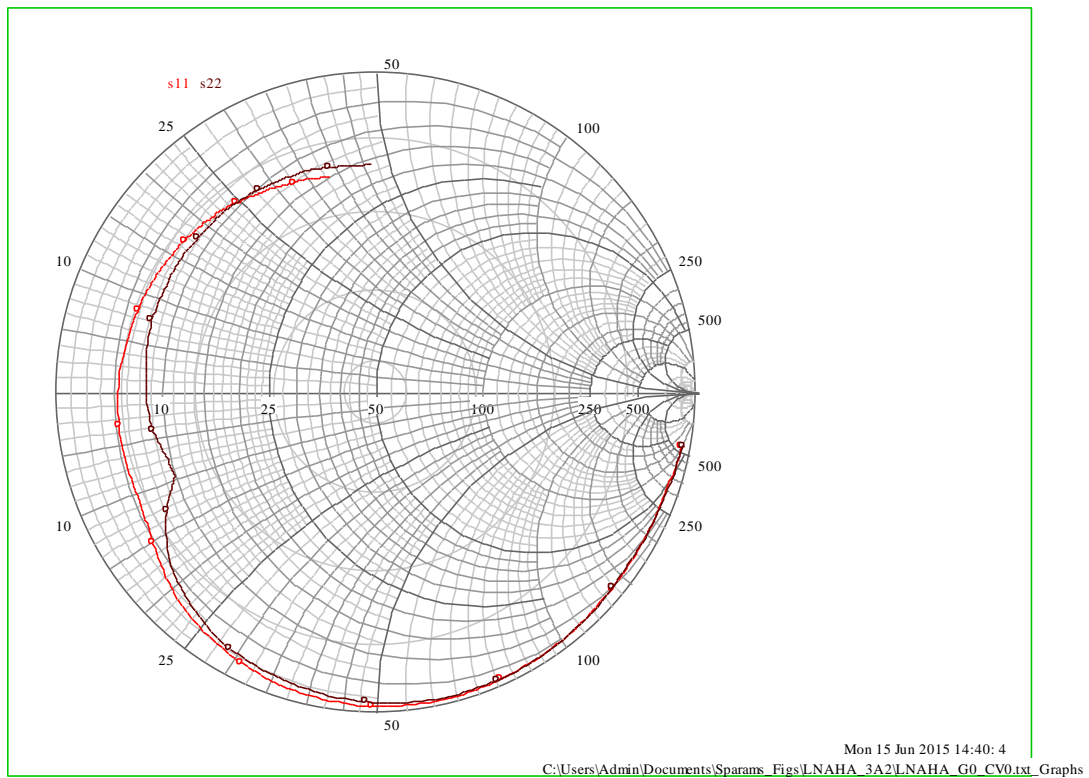


Figure 16 LNAHA Sample=2 Gain=0, Cap_Var=0

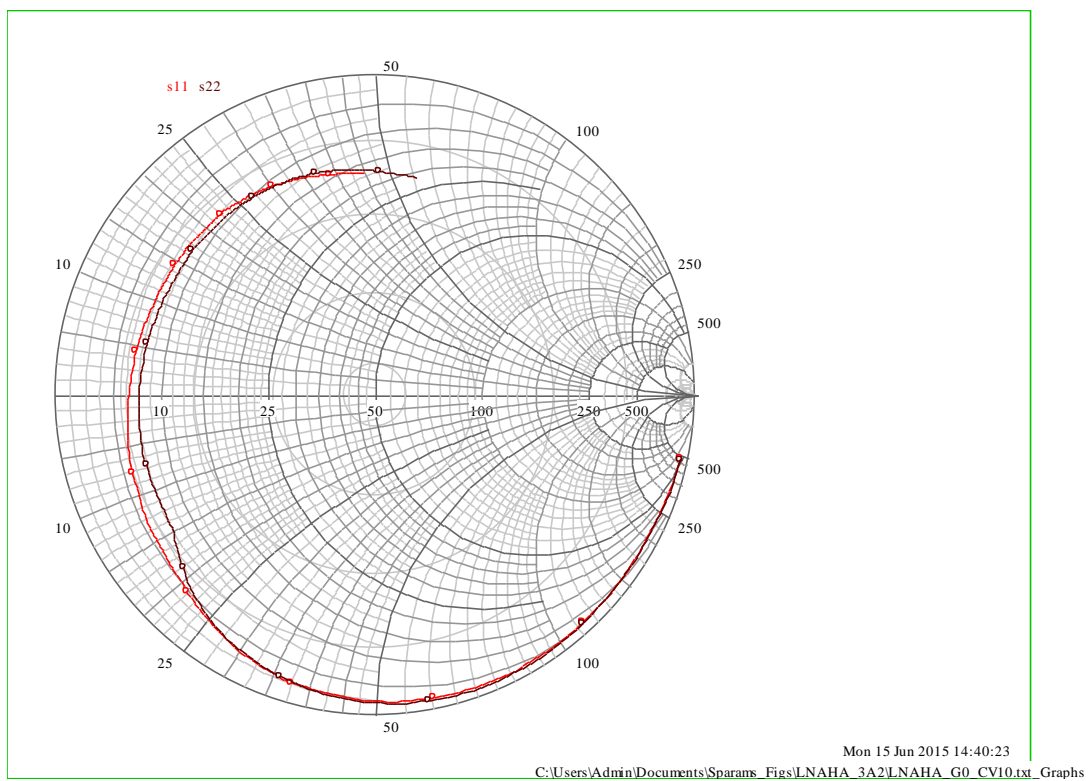


Figure 17 LNAHA Sample=2 Gain=0, Cap_Var =10

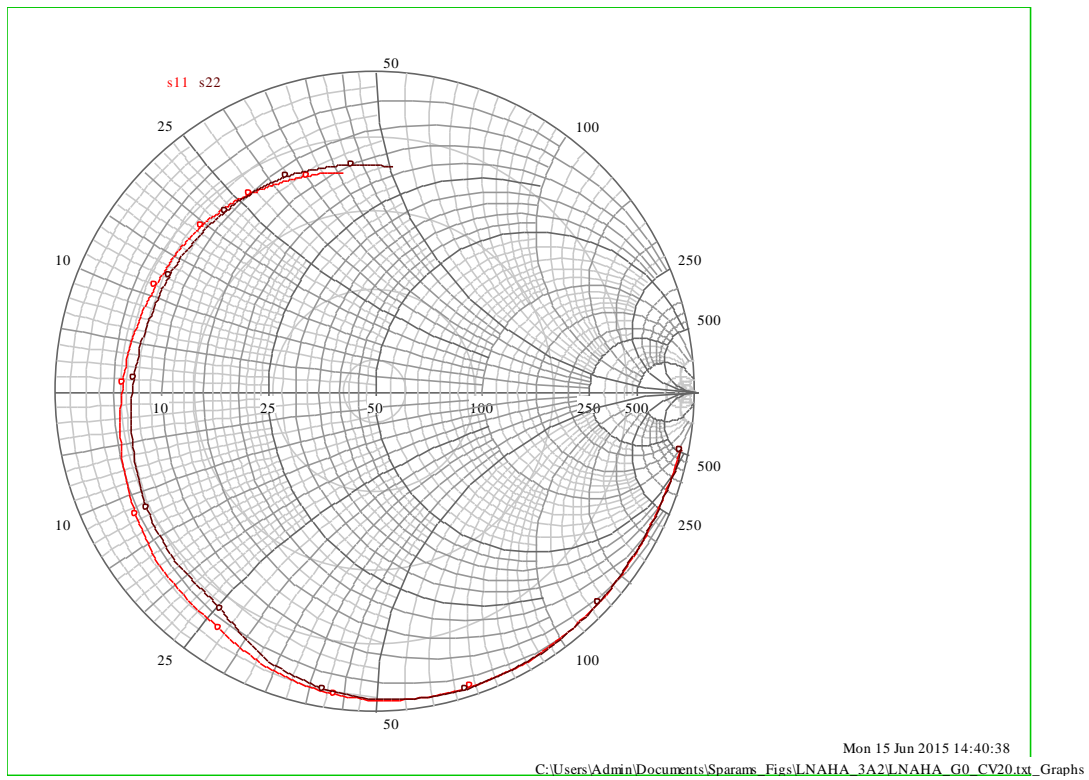


Figure 18 LNAHA Sample=2 Gain=0, Cap_Var =20

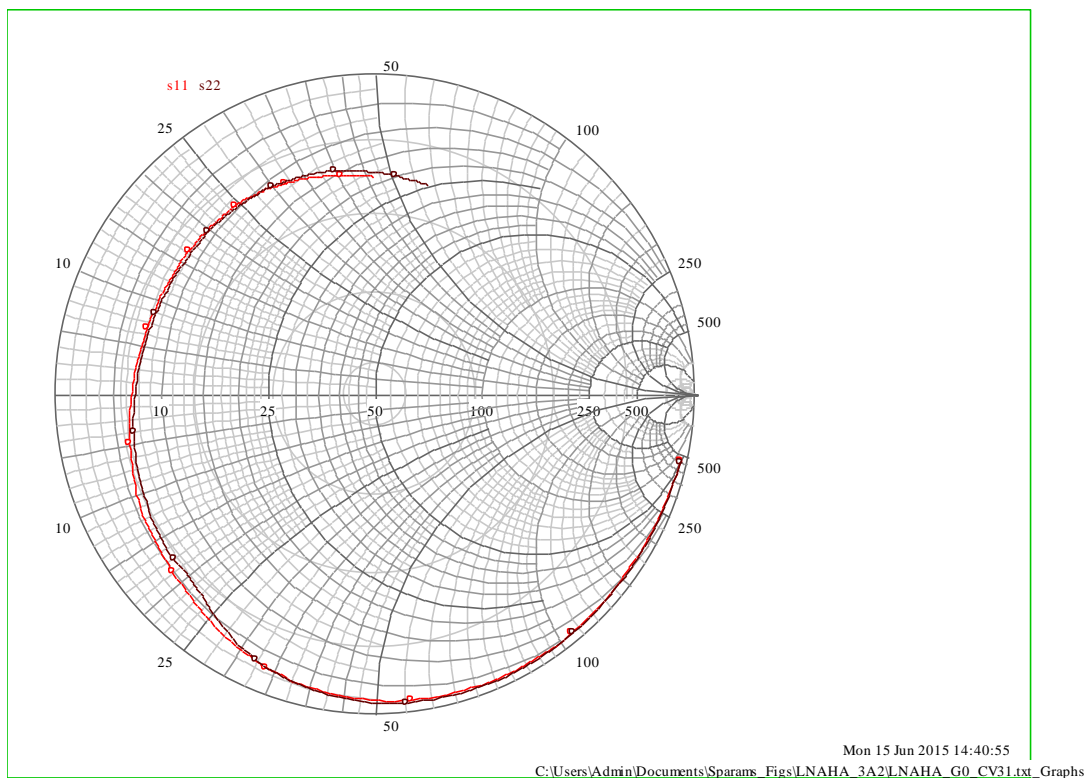


Figure 19 LNAHA Sample=2 Gain=0, Cap_Var =31

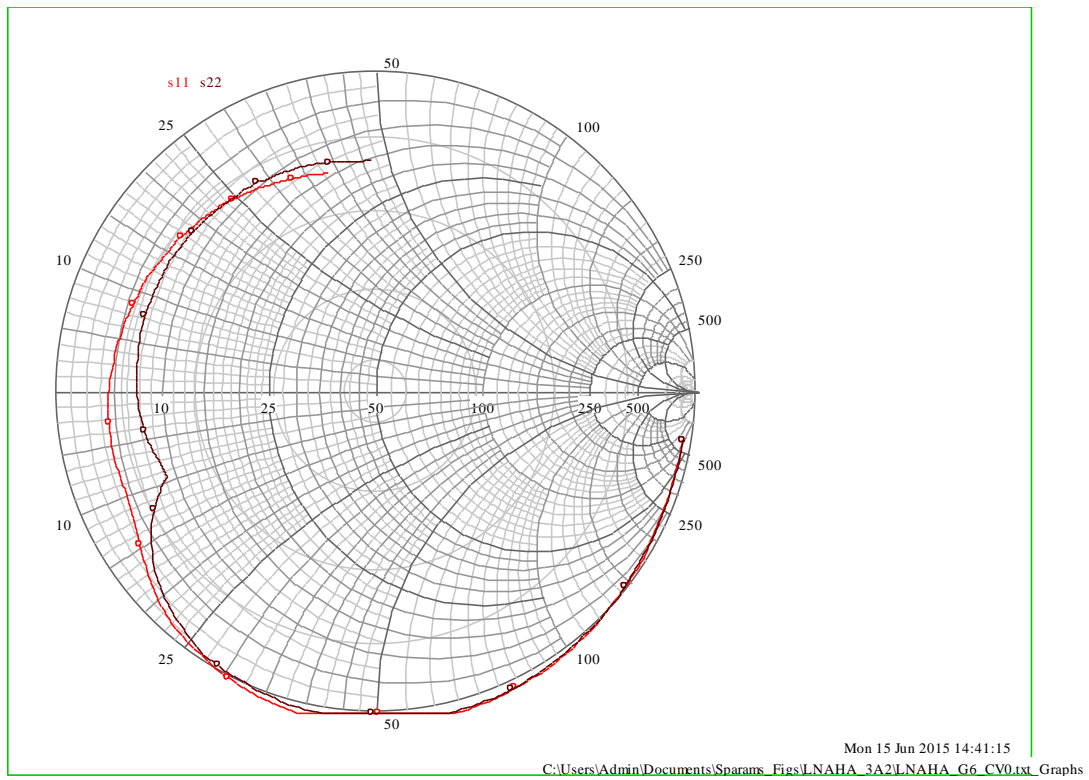


Figure 20 LNAHA Sample=2 Gain=6, Cap_Var =0

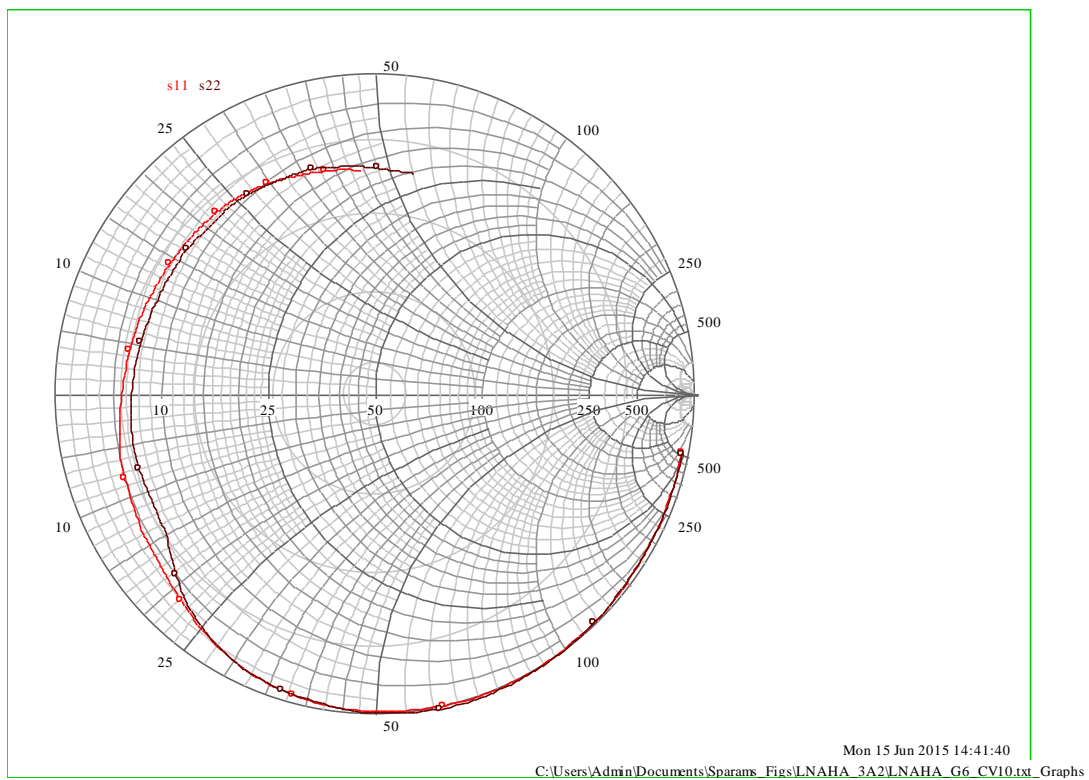


Figure 21 LNAHA Sample=2 Gain=6, Cap_Var =10

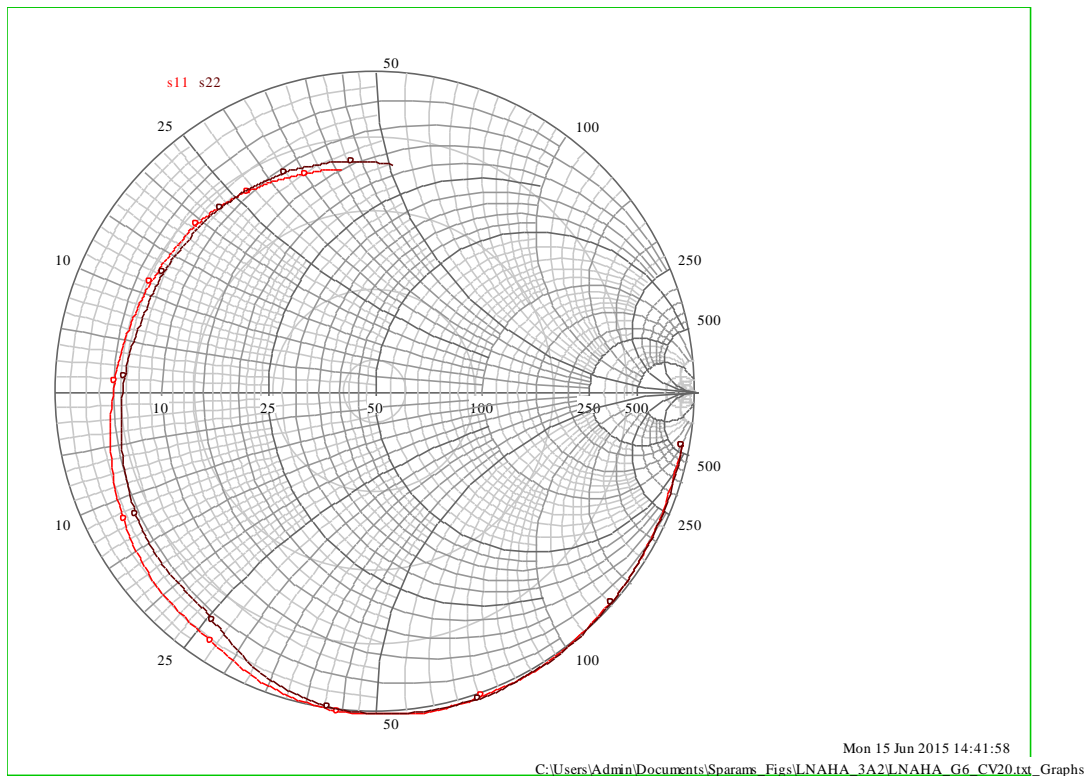


Figure 22 LNAHA Sample=2 Gain=6, Cap_Var =20

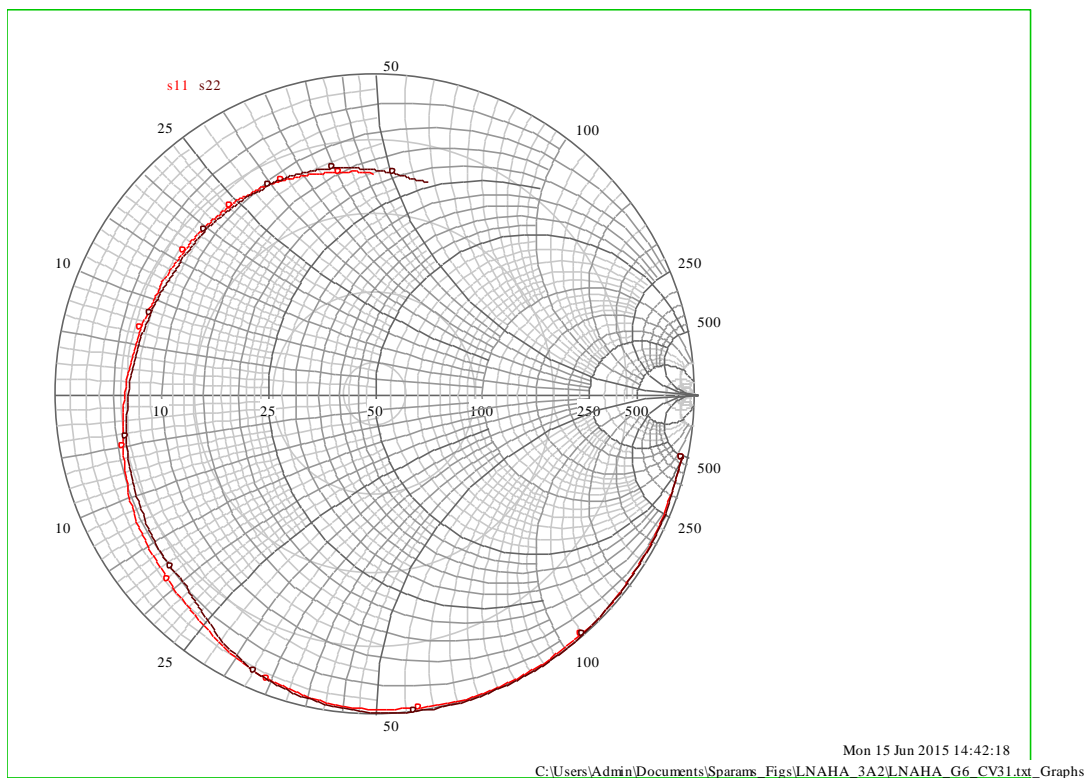


Figure 23 LNAHA Sample=2 Gain=6, Cap_Var =31

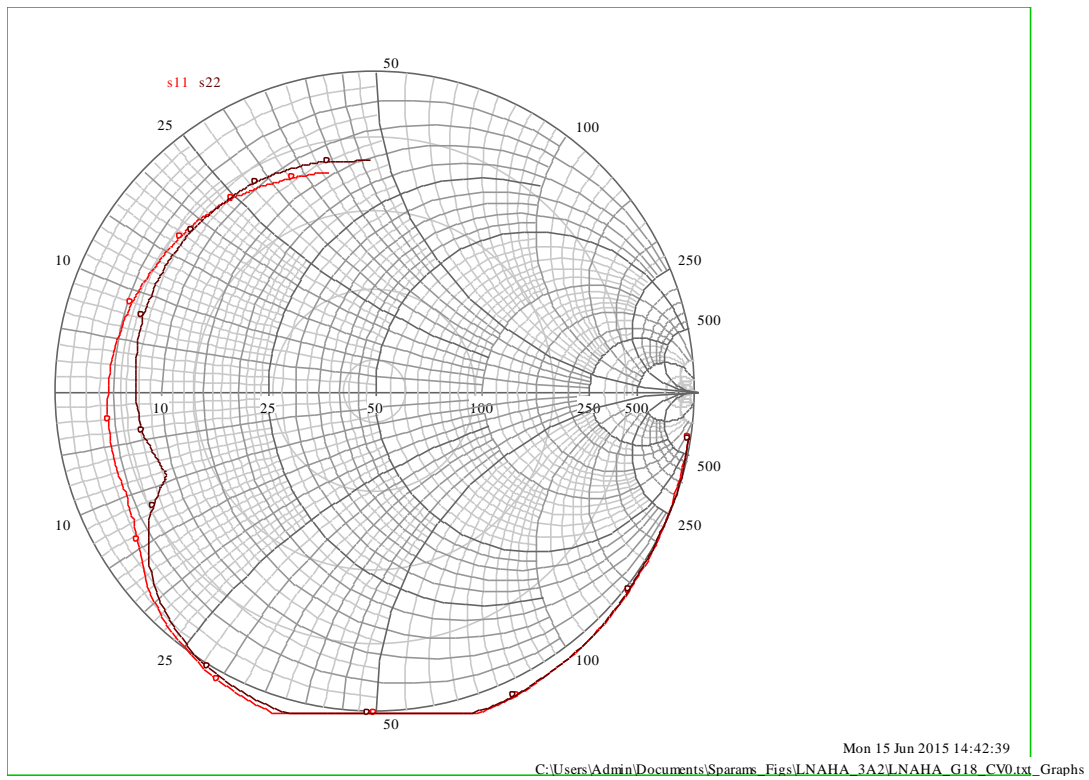


Figure 24 LNAHA Sample=2 Gain=18, Cap_Var =0

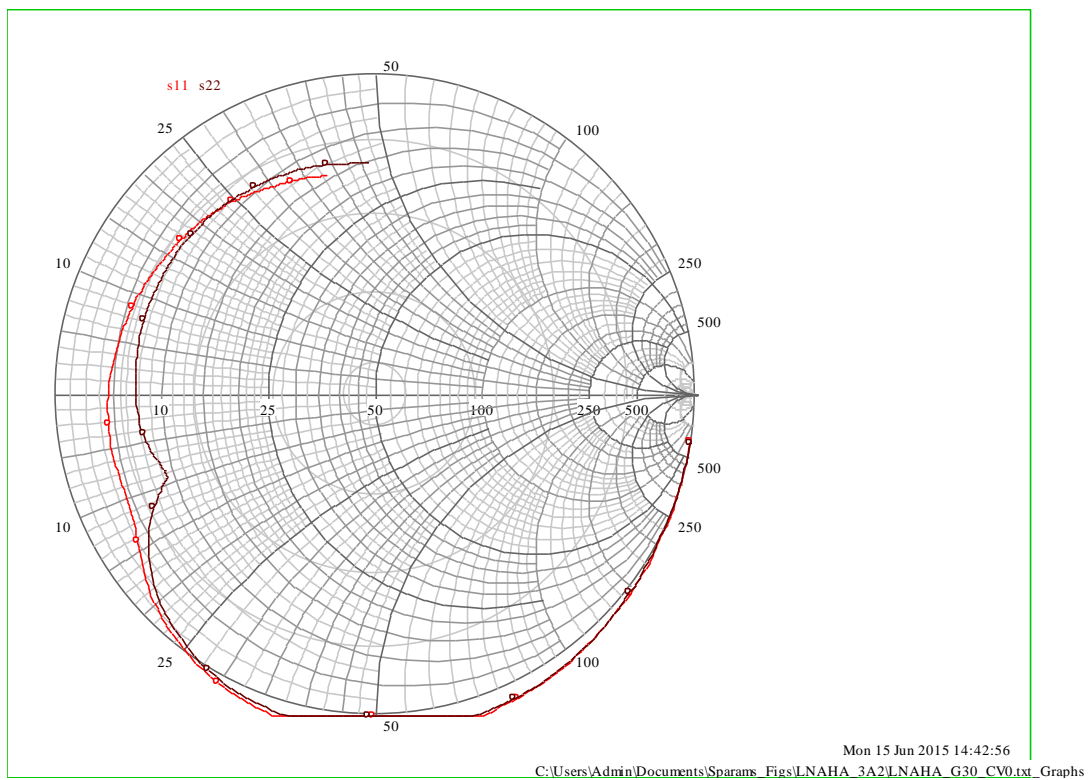


Figure 25 LNAHA Sample=2 Gain=31, Cap_Var =0

4.3 LNAH Channel A Sample 3

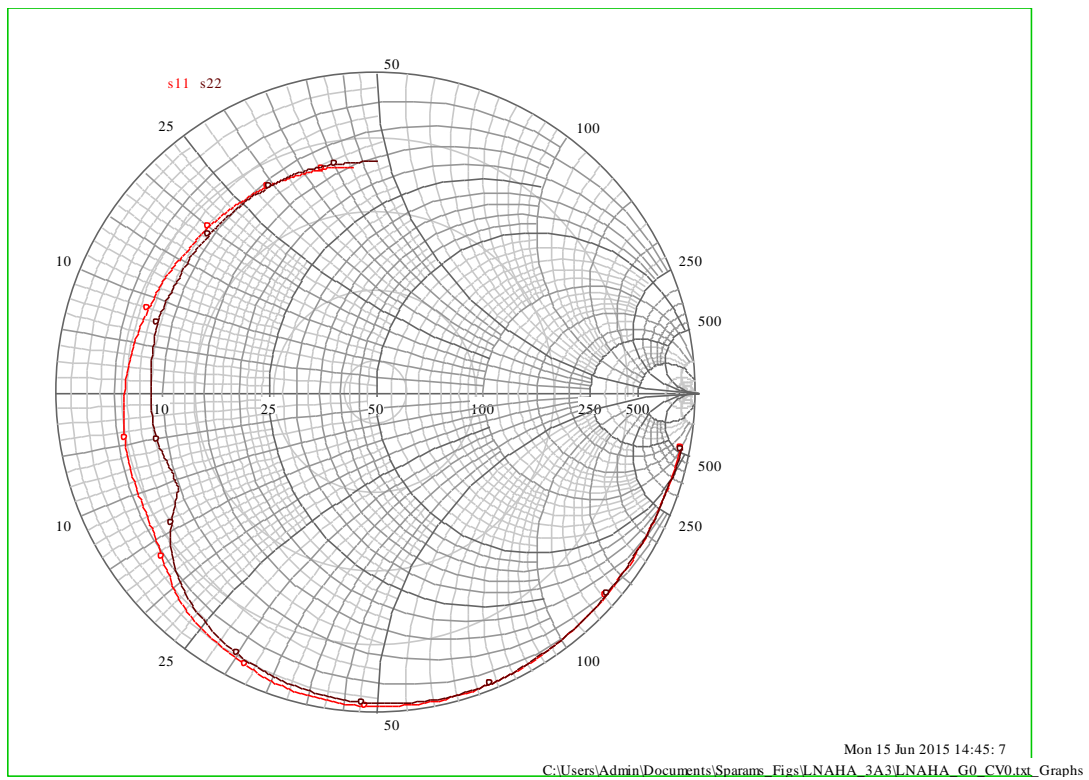


Figure 26 LNAHA Sample=3 Gain=0, Cap_Var=0

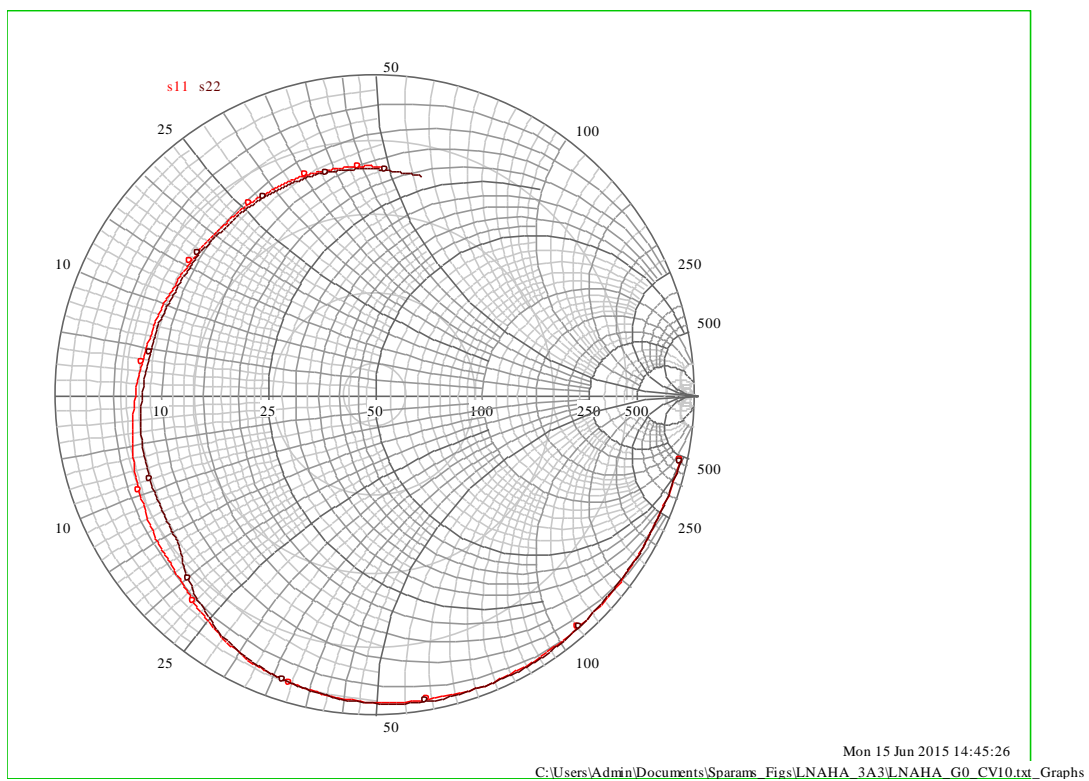


Figure 27 LNAHA Sample=3 Gain=0, Cap_Var =10

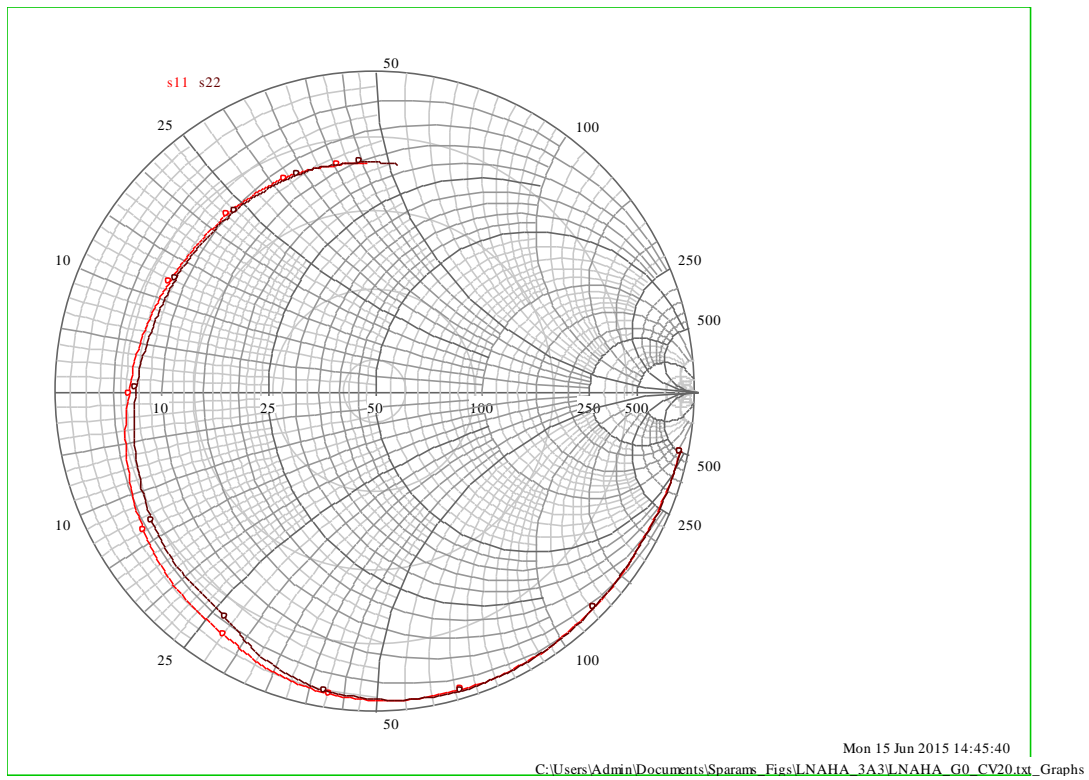


Figure 28 LNAHA Sample=3 Gain=0, Cap_Var =20

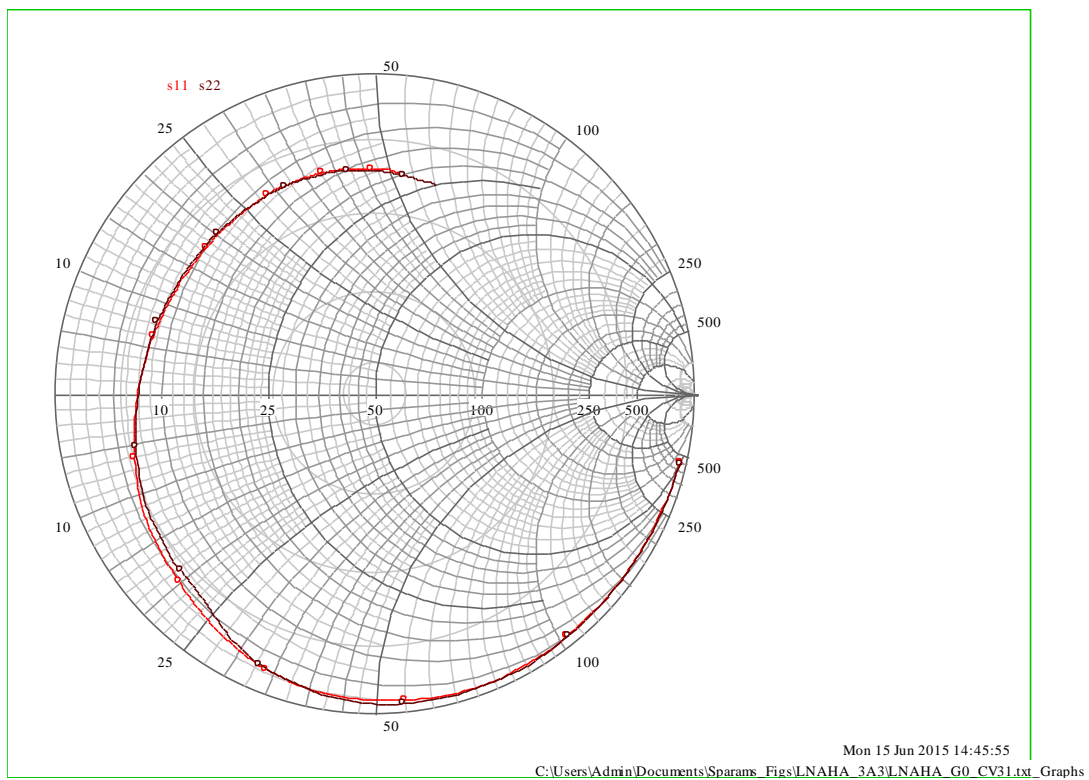


Figure 29 LNAHA Sample=3 Gain=0, Cap_Var =31

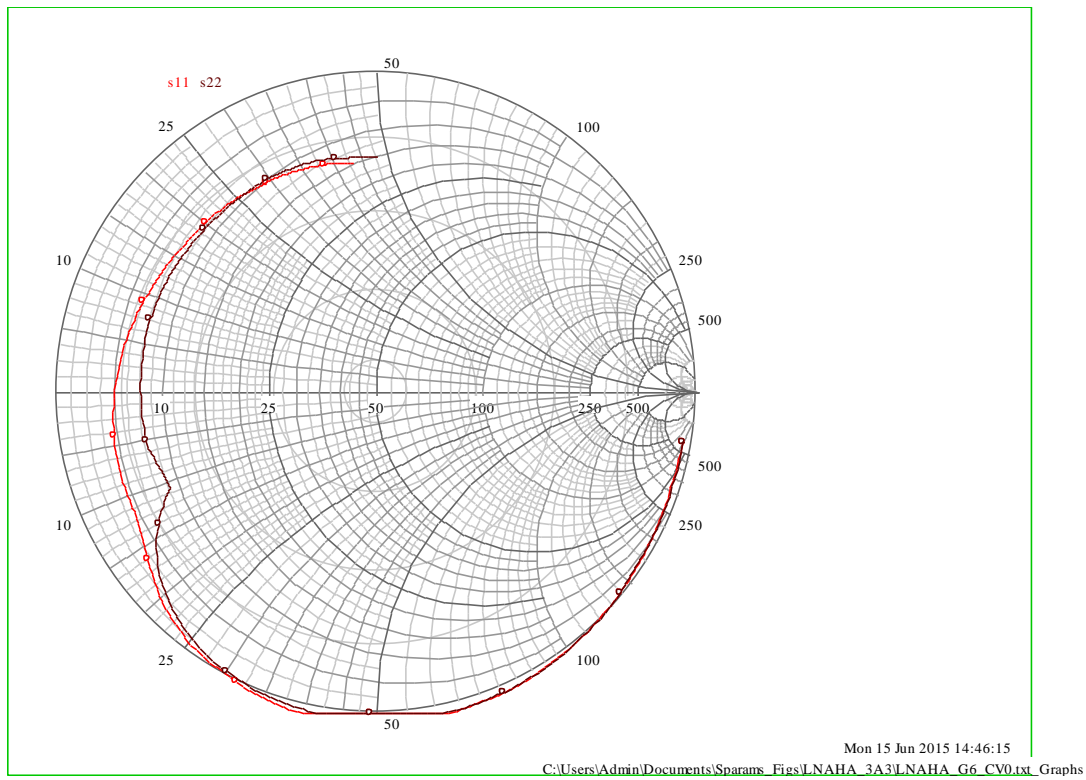


Figure 30 LNAHA Sample=3 Gain=6, Cap_Var =0

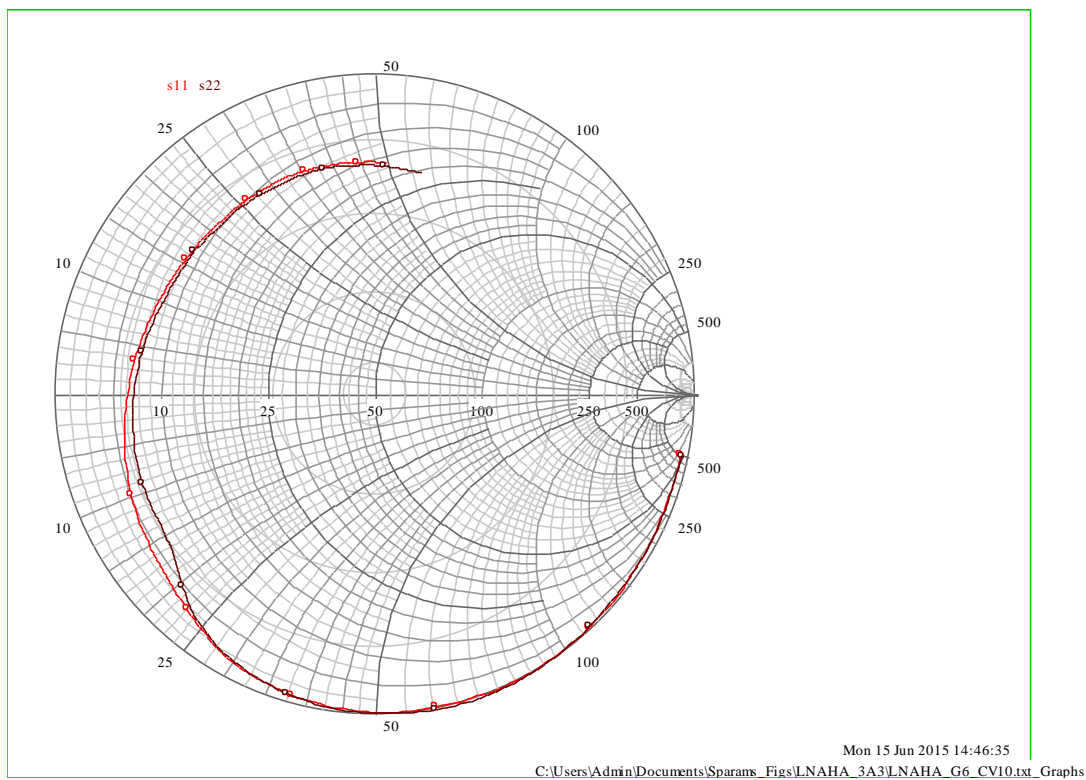


Figure 31 LNAHA Sample=3 Gain=6, Cap_Var =10

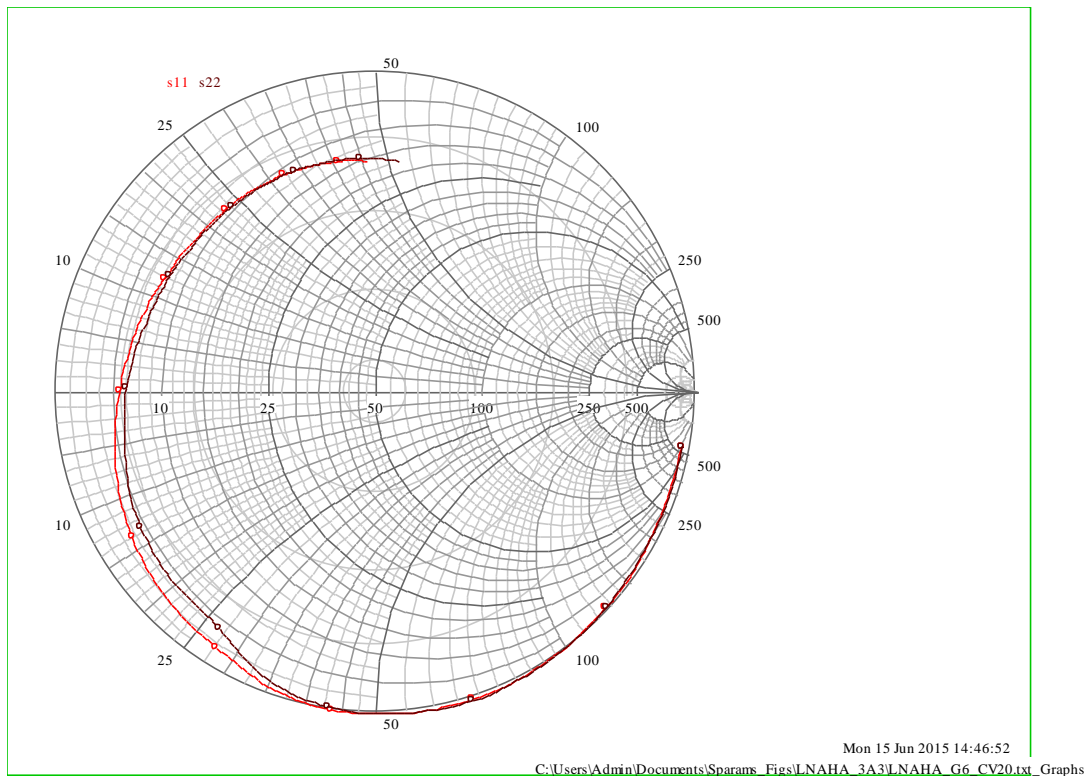


Figure 32 LNAHA Sample=3 Gain=6, Cap_Var =20

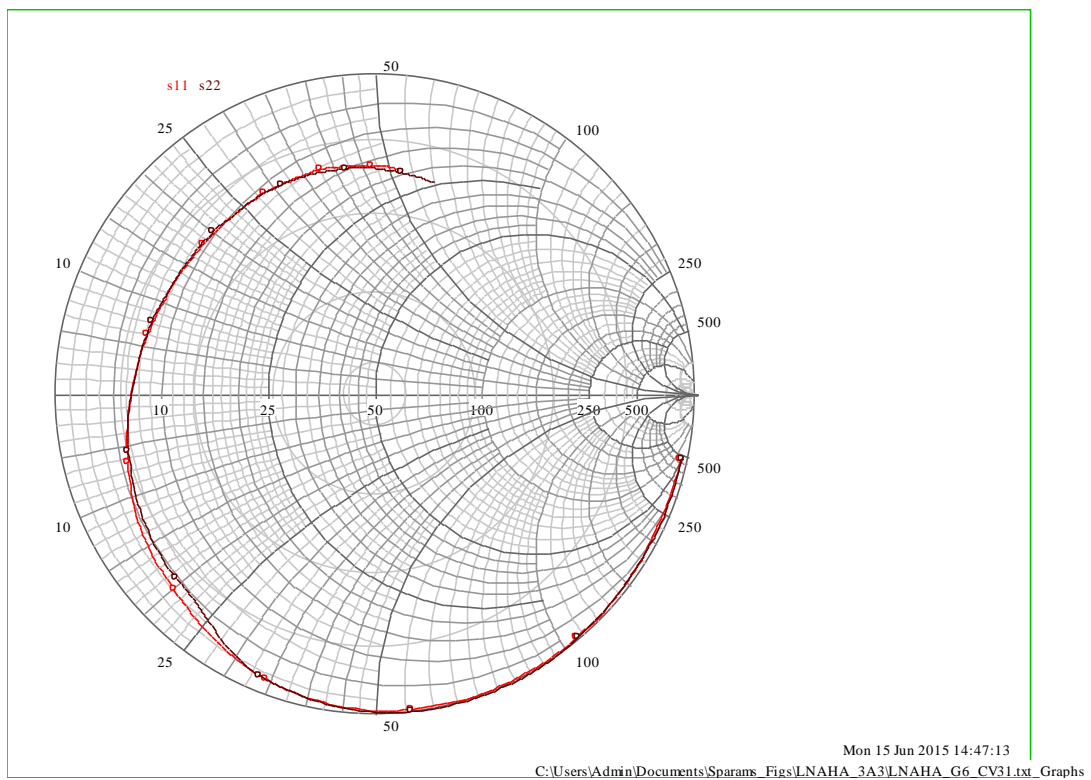


Figure 33 LNAHA Sample=3 Gain=6, Cap_Var =31

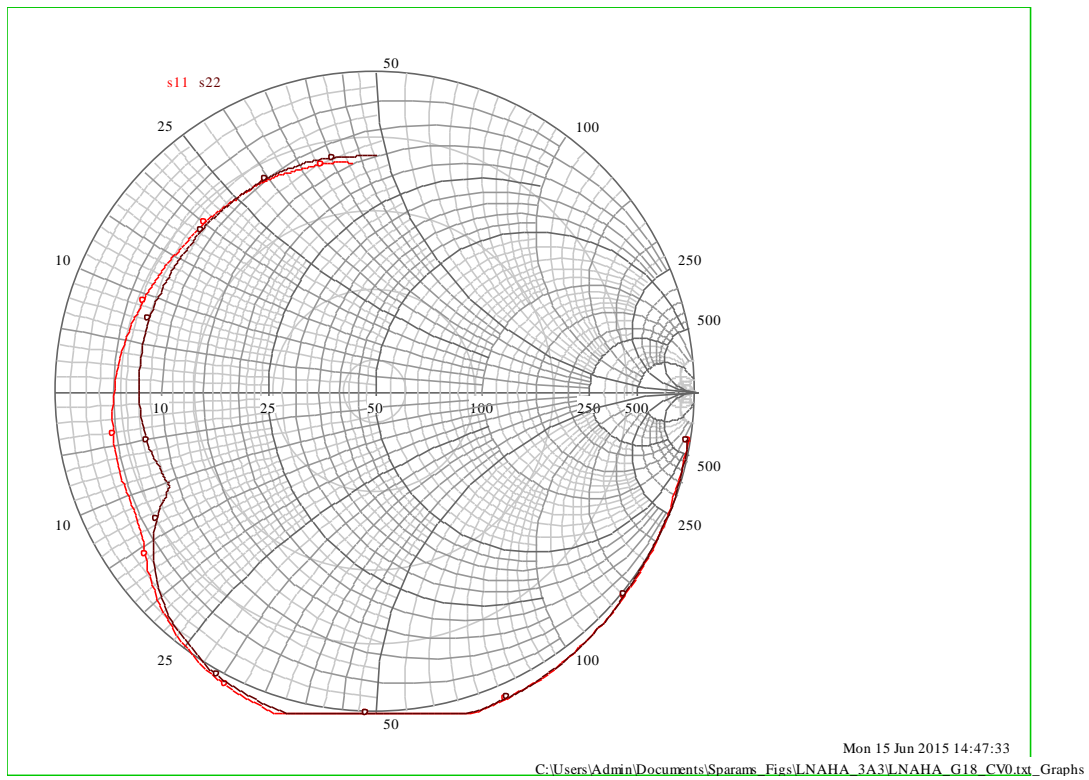


Figure 34 LNAHA Sample=3 Gain=18, Cap_Var =0

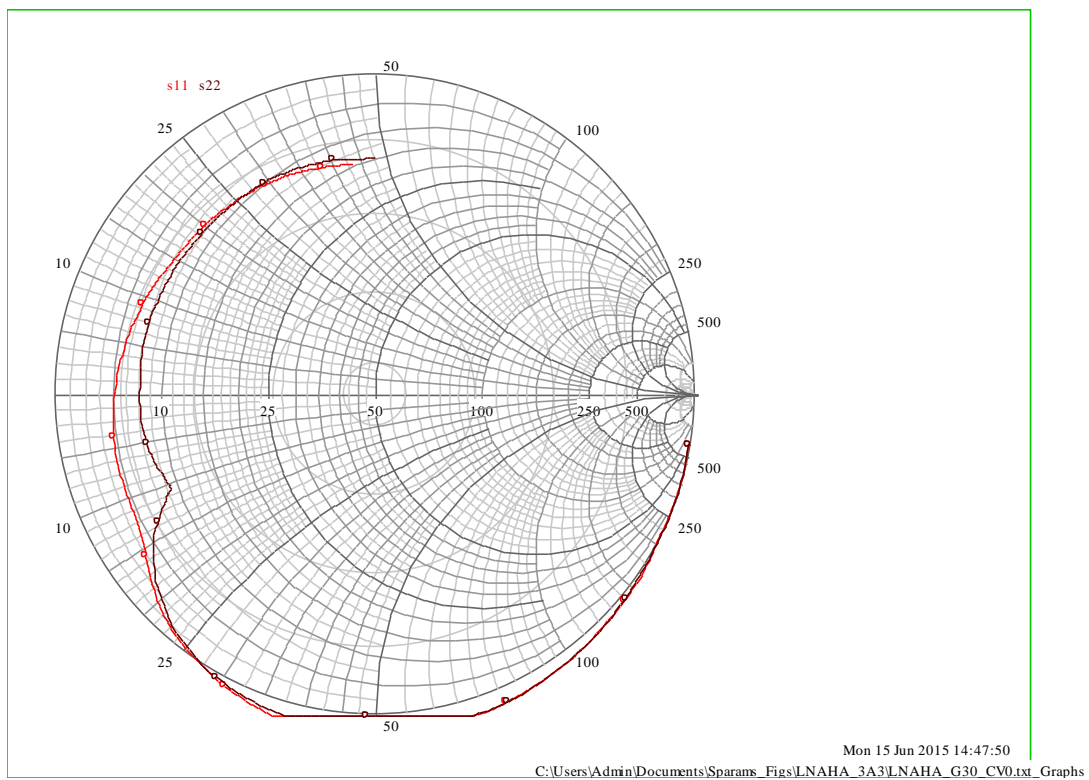


Figure 35 LNAHA Sample=3 Gain=31, Cap_Var =0

4.4 LNAH Channel B Sample 2

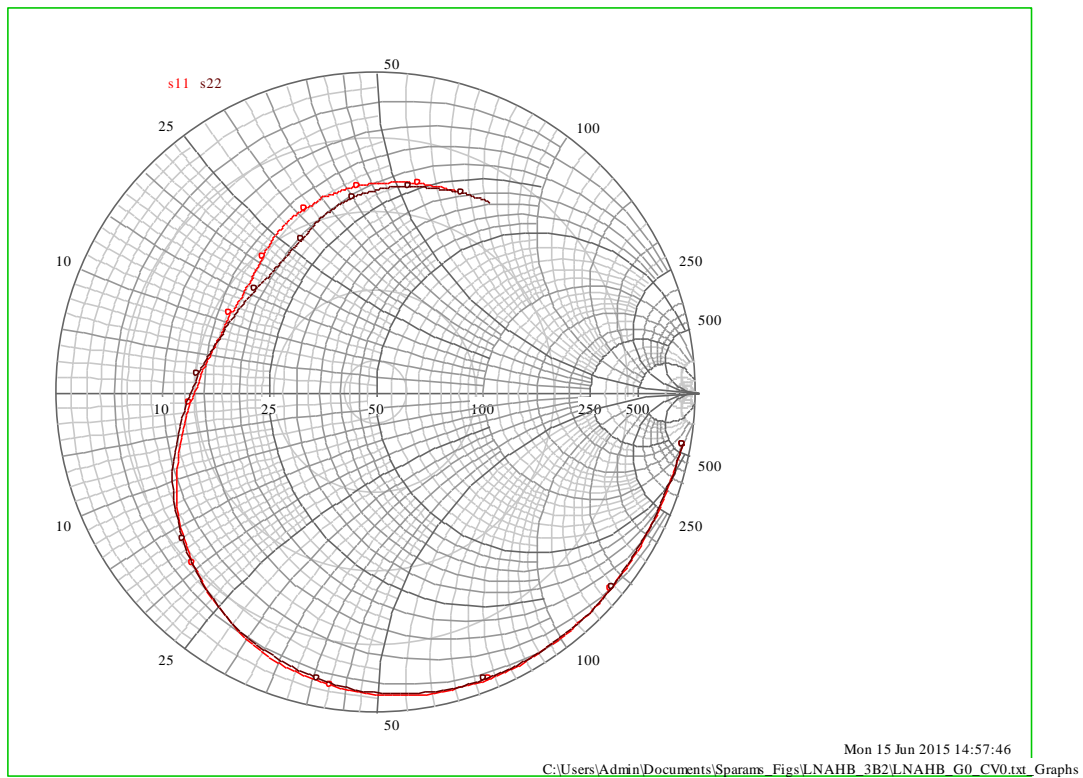


Figure 36 LNAHB Sample=2 Gain=0, Cap_Var=0

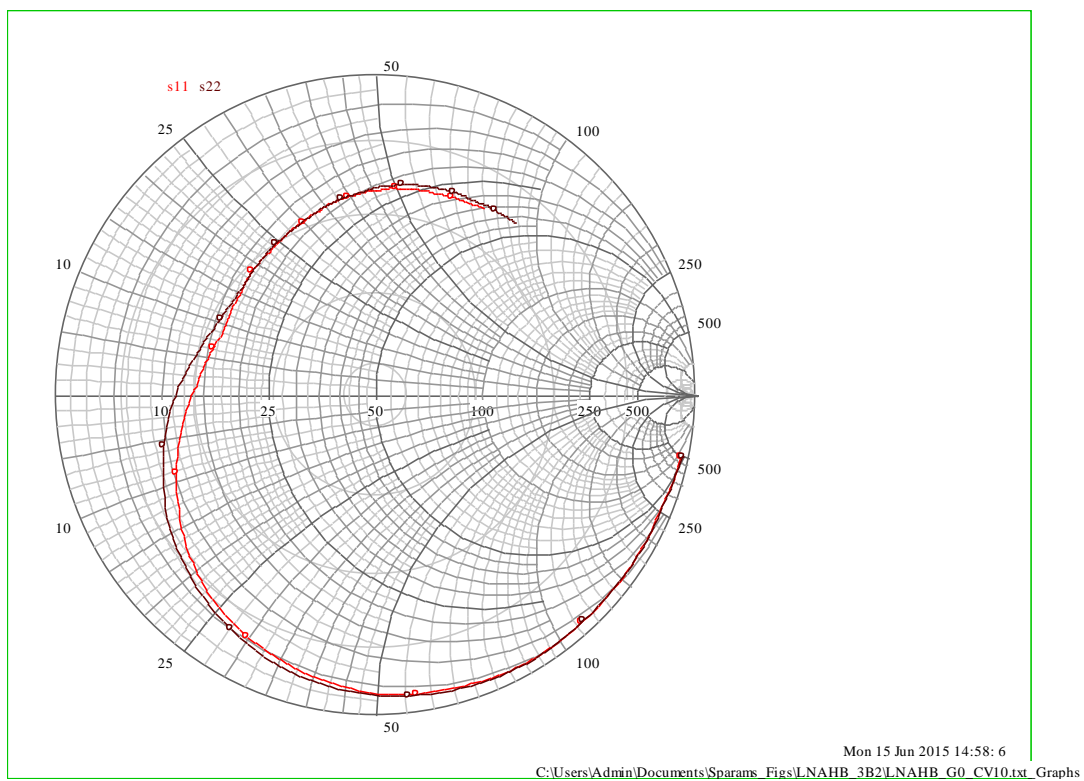


Figure 37 LNAHB Sample=2 Gain=0, Cap_Var =10

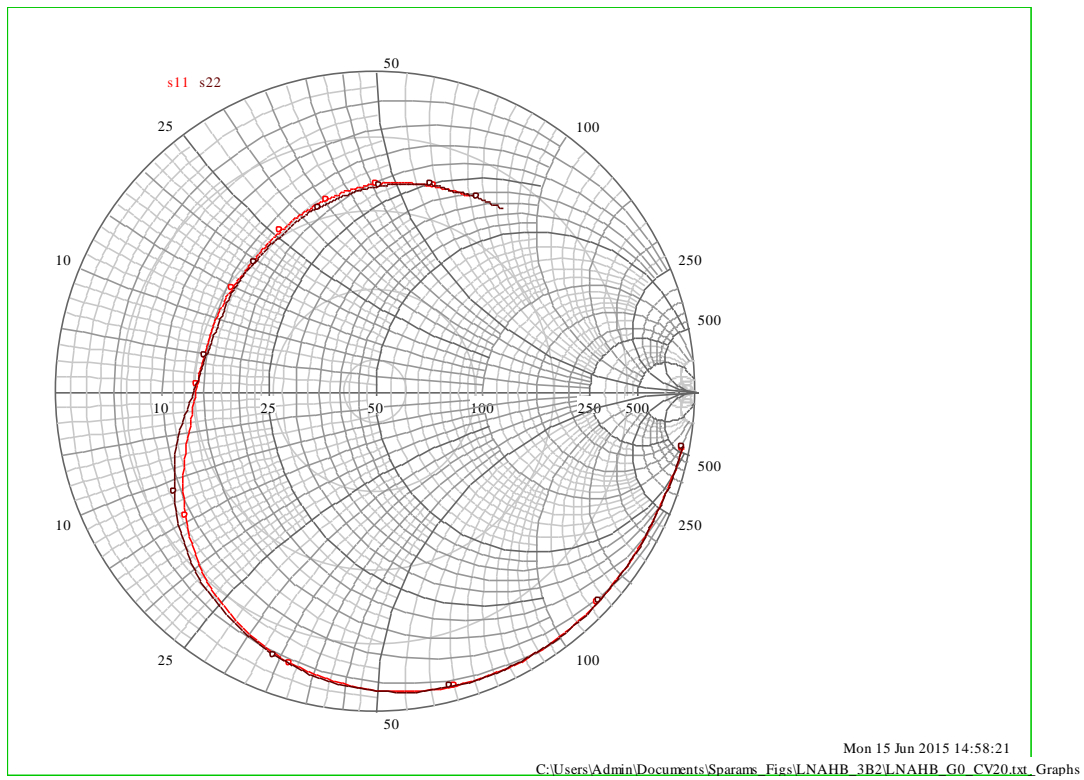


Figure 38 LNAHB Sample=2 Gain=0, Cap_Var =20

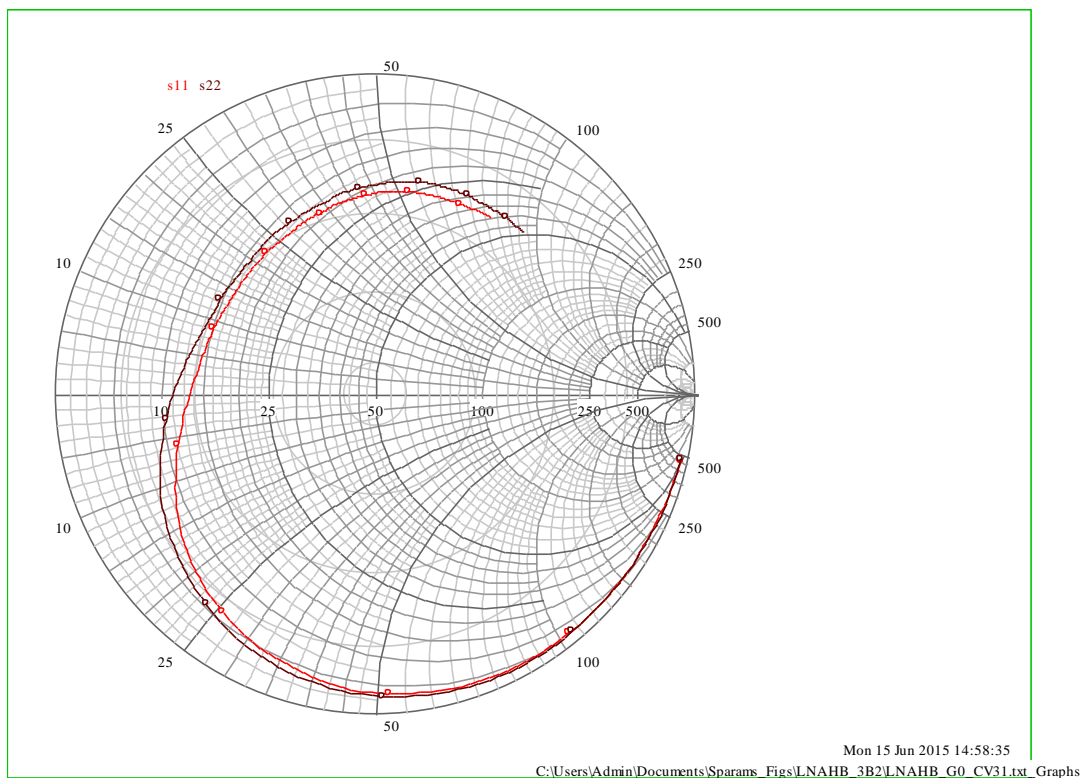


Figure 39 LNAHB Sample=2 Gain=0, Cap_Var =31

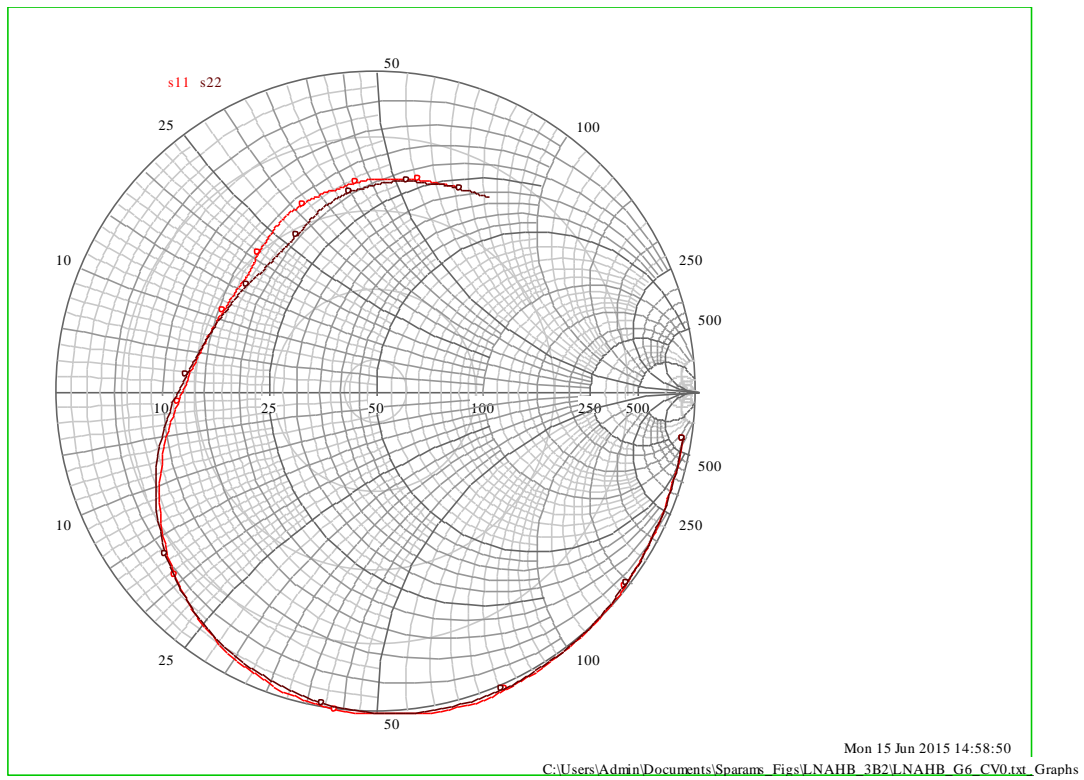


Figure 40 LNAHB Sample=2 Gain=6, Cap_Var =0

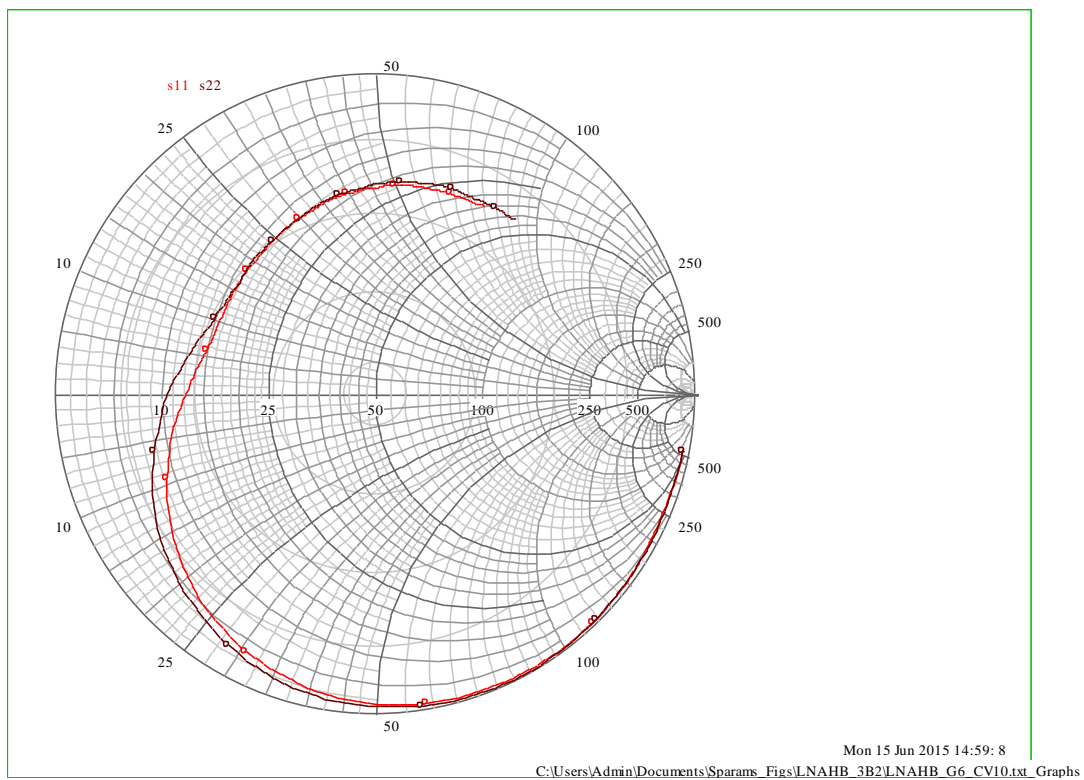


Figure 41 LNAHB Sample=2 Gain=6, Cap_Var =10

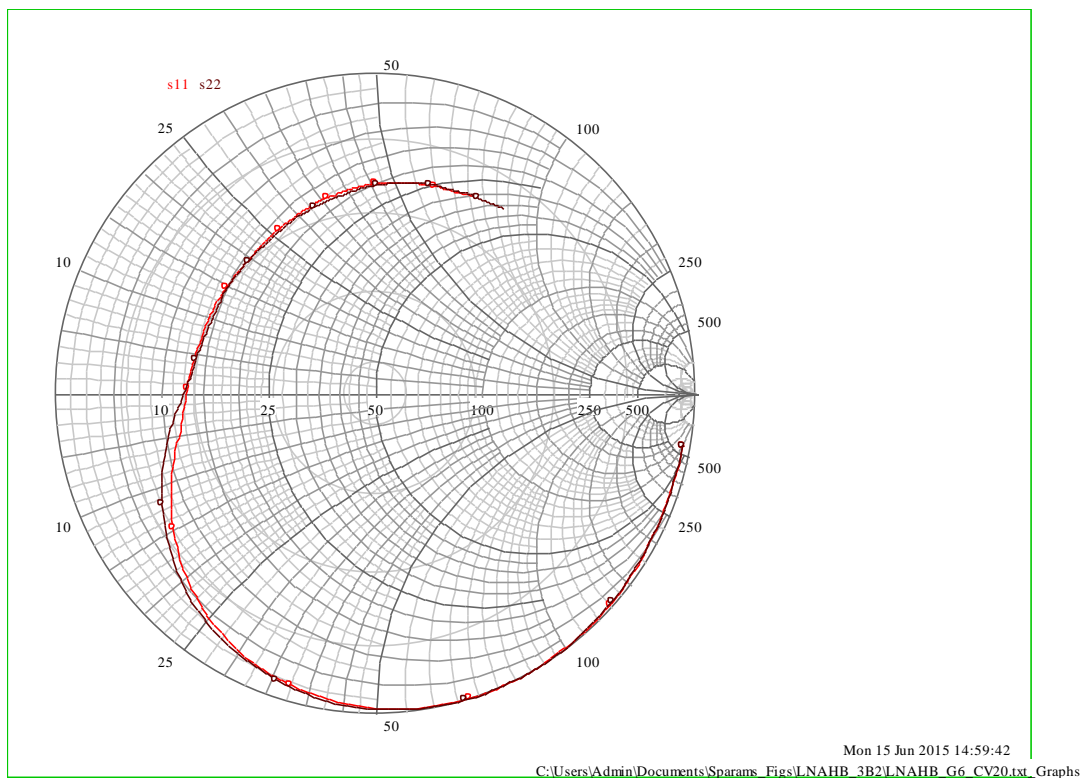


Figure 42 LNAHB Sample=2 Gain=6, Cap_Var =20

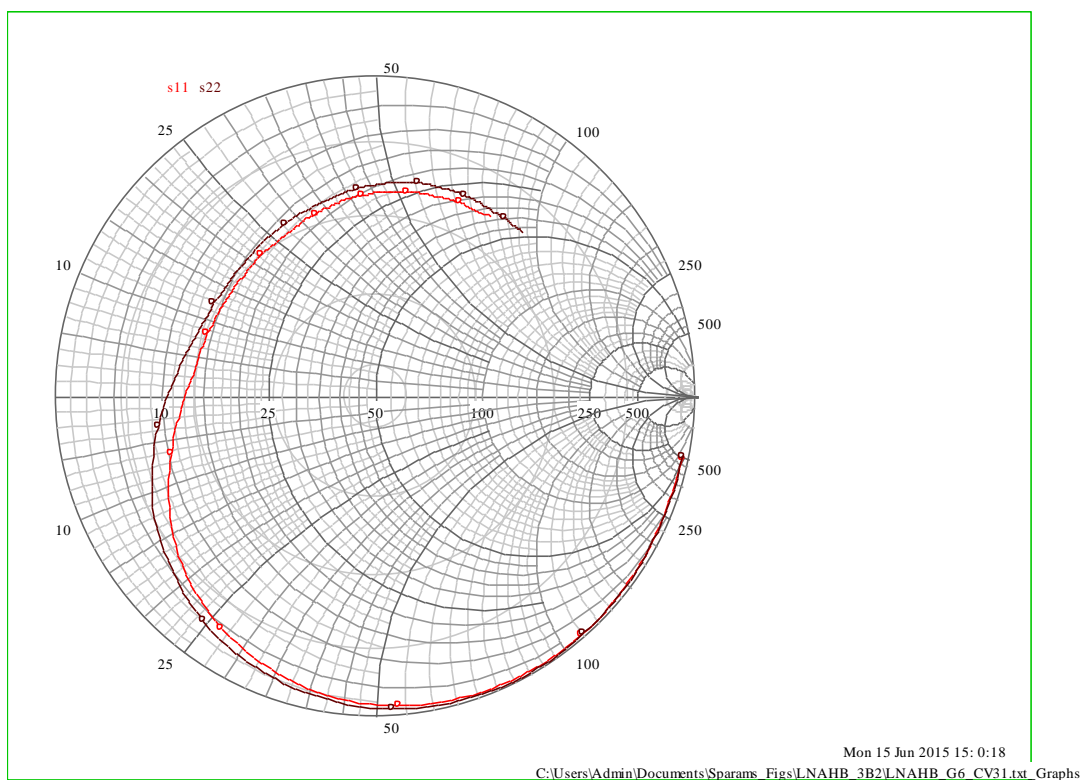


Figure 43 LNAHB Sample=2 Gain=6, Cap_Var =31

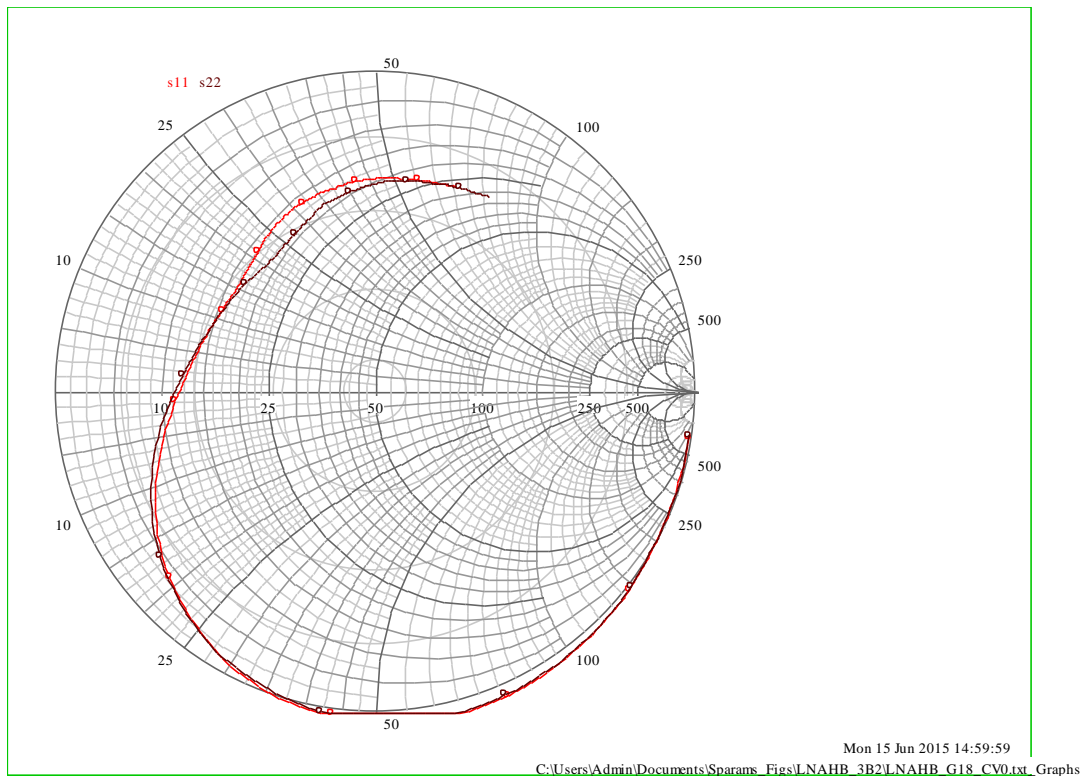


Figure 44 LNAHB Sample=2 Gain=18, Cap_Var =0

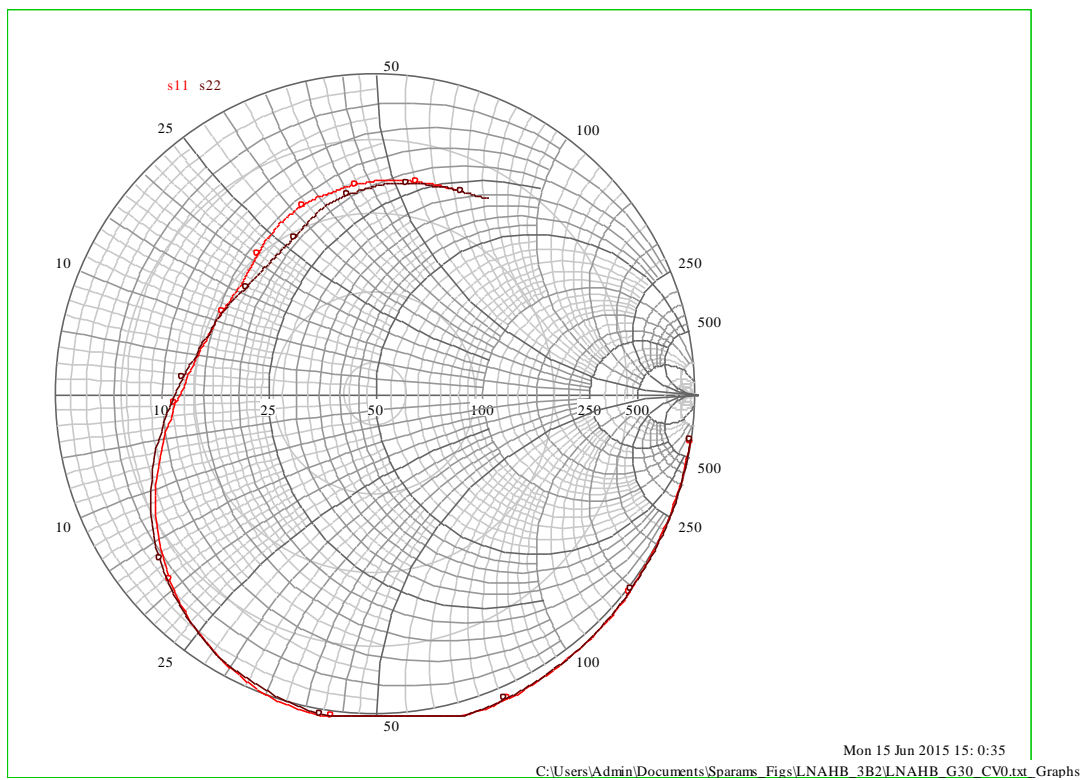


Figure 45 LNAHB Sample=2 Gain=31, Cap_Var =0

4.5 LNAH Channel B Sample 3

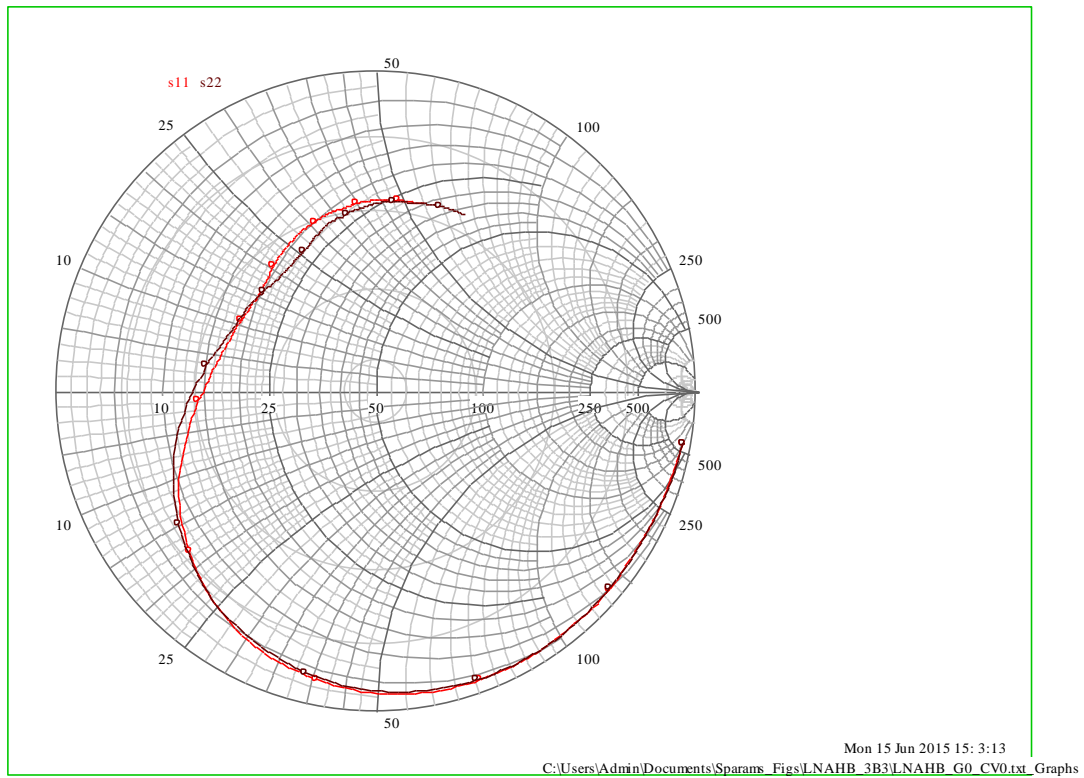


Figure 46 LNAHB Sample=3 Gain=0, Cap_Var=0

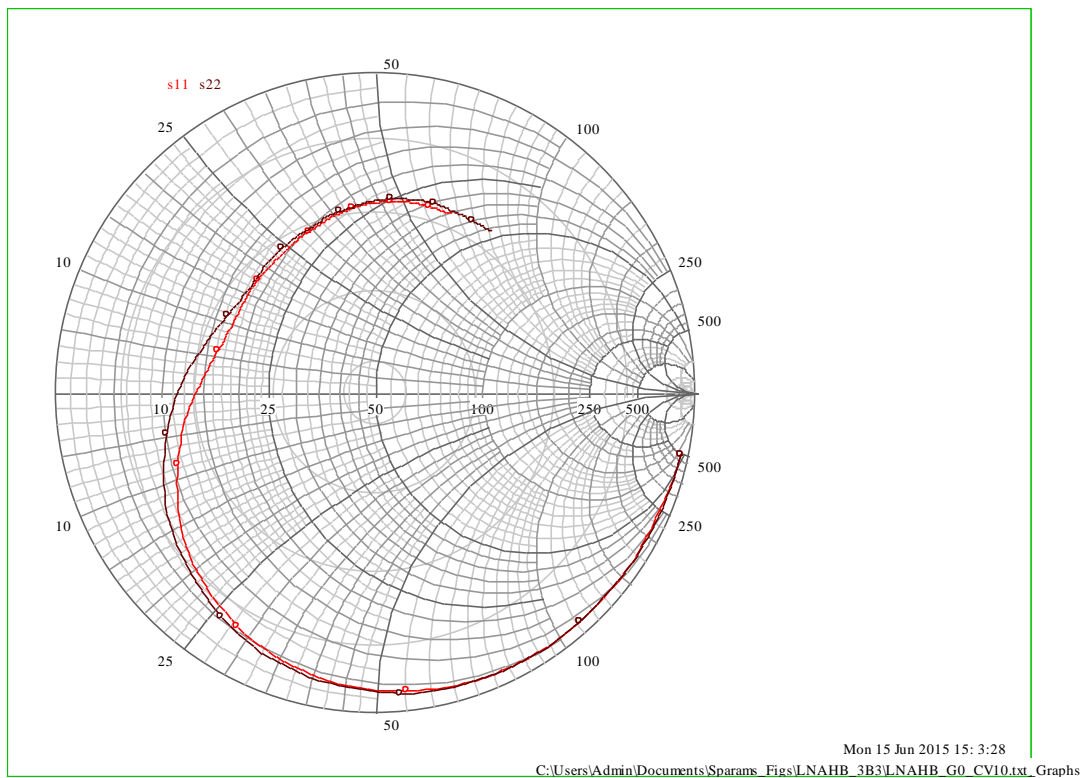


Figure 47 LNAHB Sample=3 Gain=0, Cap_Var =10

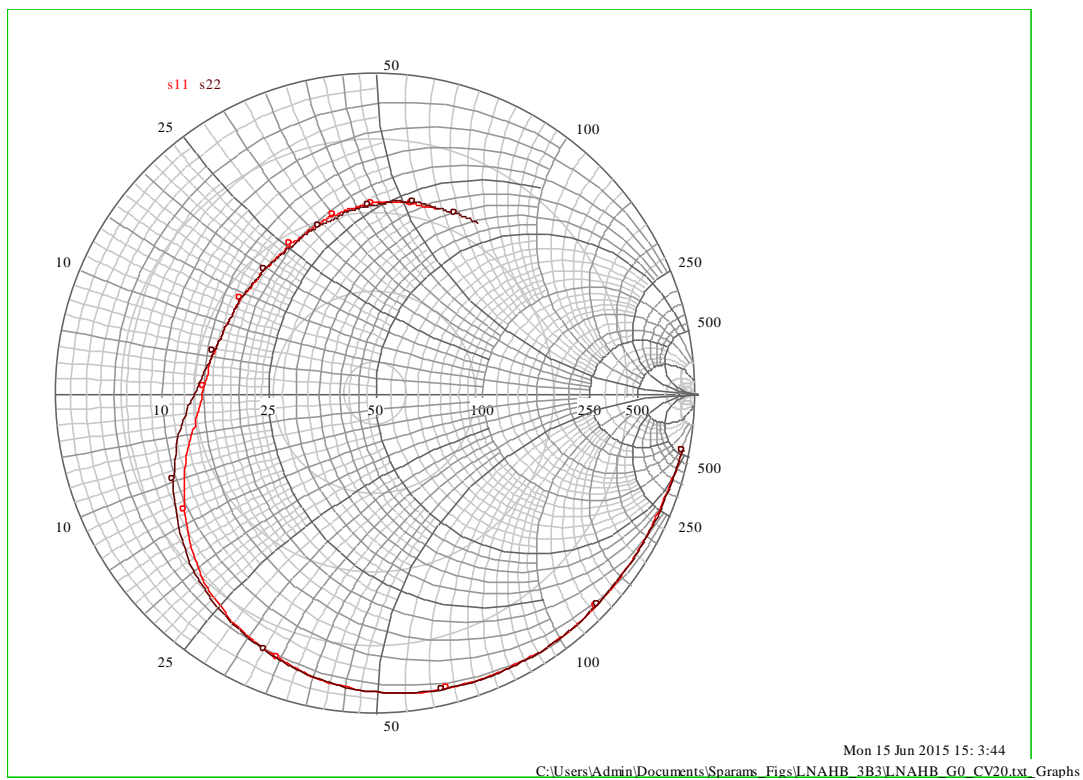


Figure 48 LNAHB Sample=3 Gain=0, Cap_Var =20

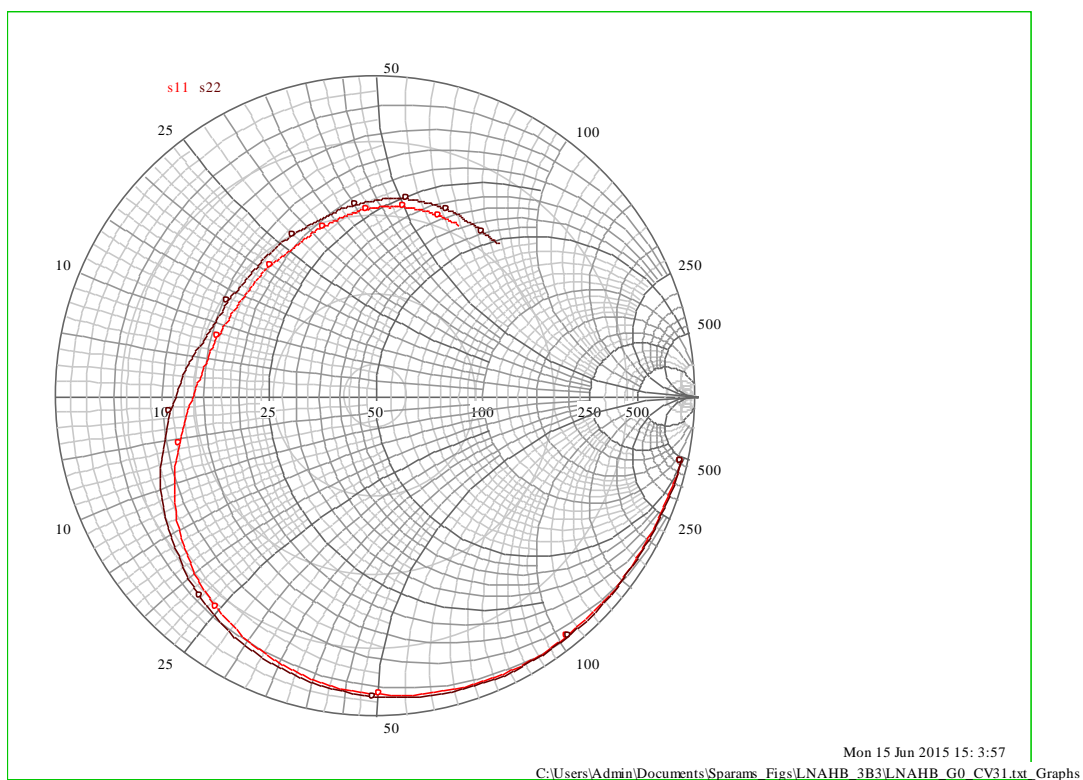


Figure 49 LNAHB Sample=3 Gain=0, Cap_Var =31

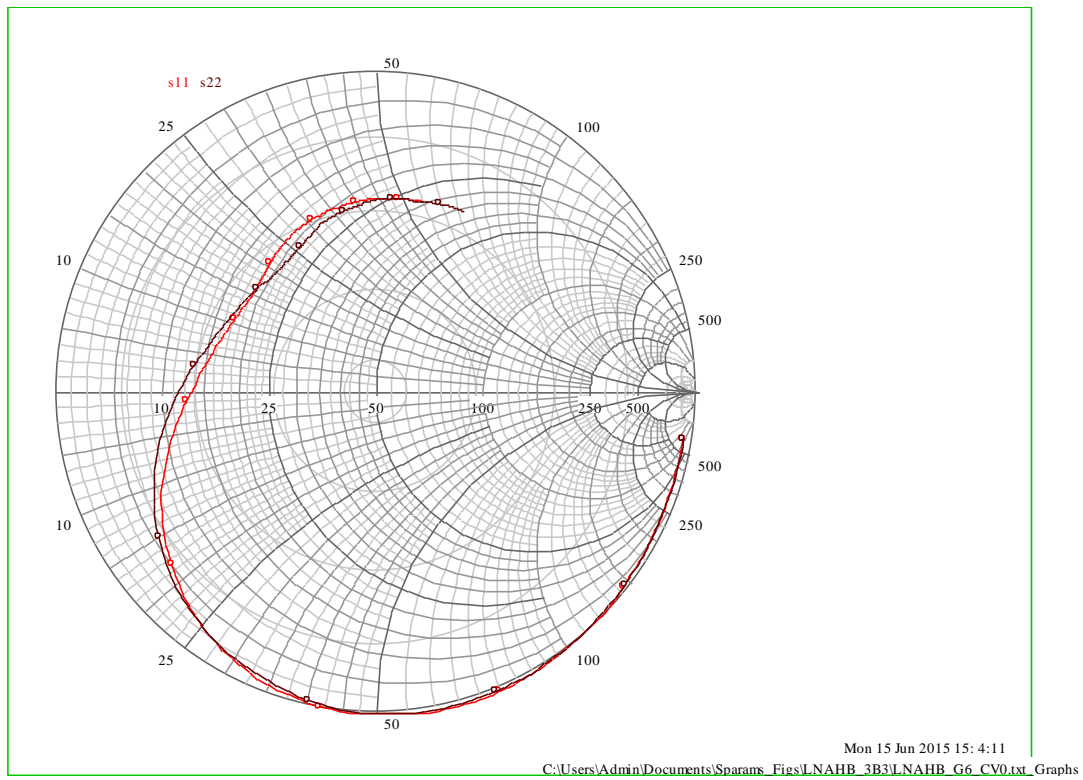


Figure 50 LNAHB Sample=3 Gain=6, Cap_Var =0

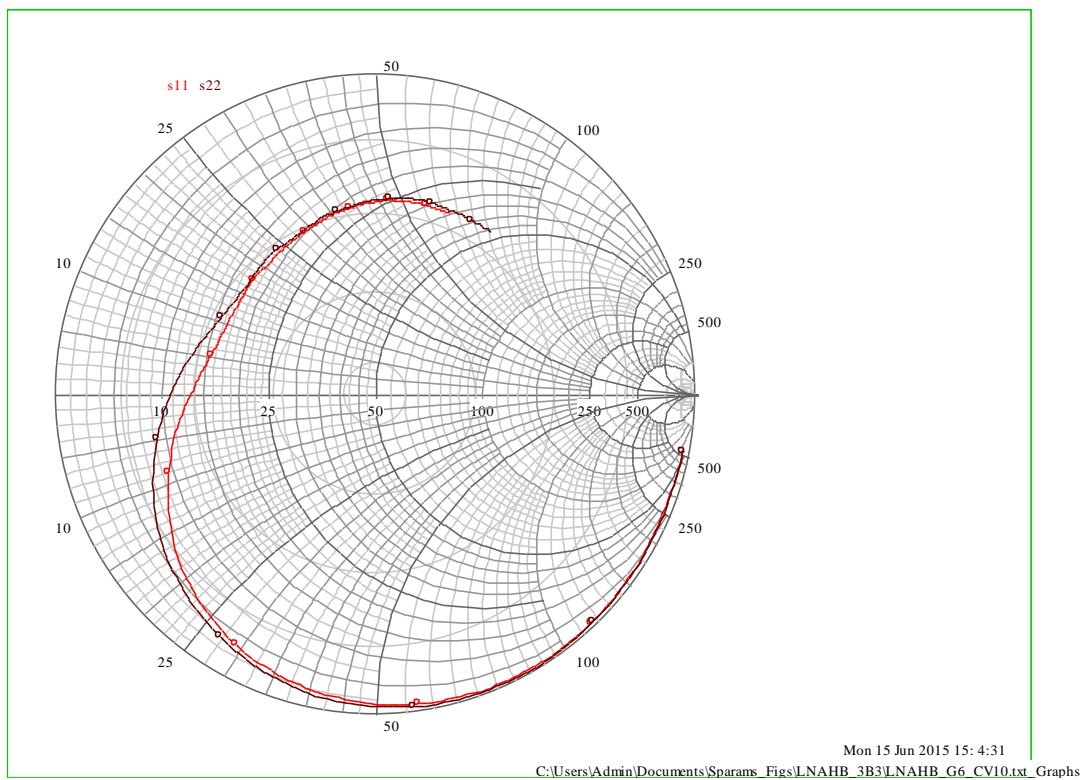


Figure 51 LNAHB Sample=3 Gain=6, Cap_Var =10

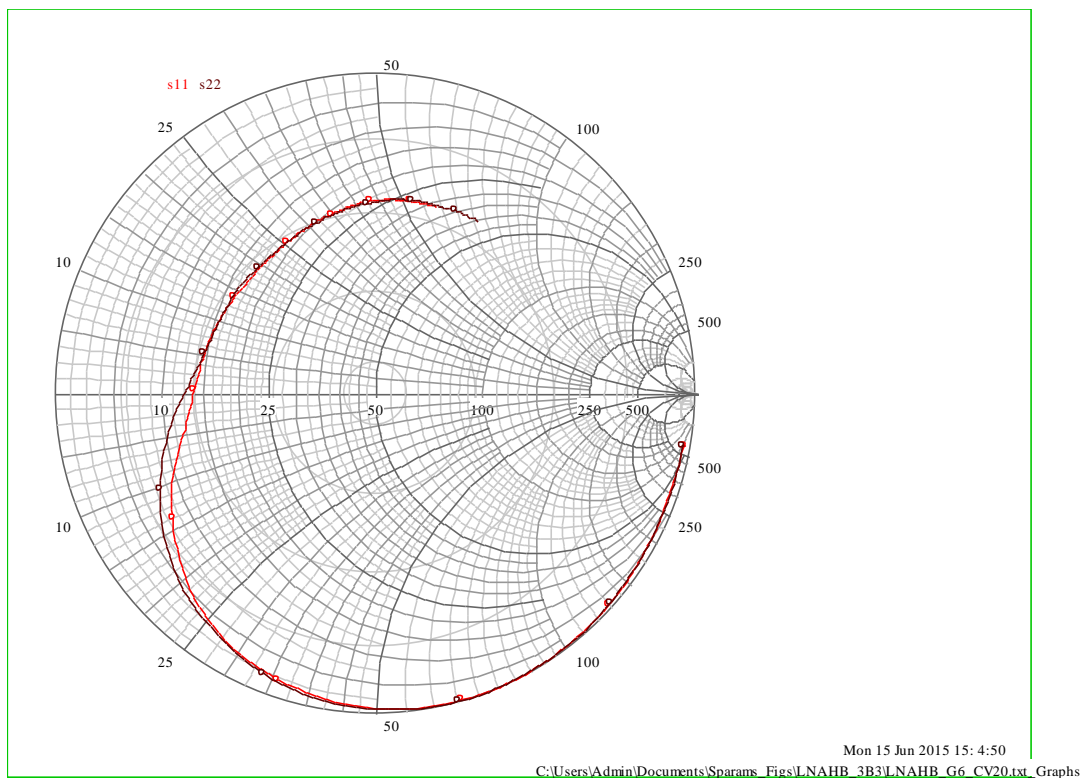


Figure 52 LNAHB Sample=3 Gain=6, Cap_Var =20

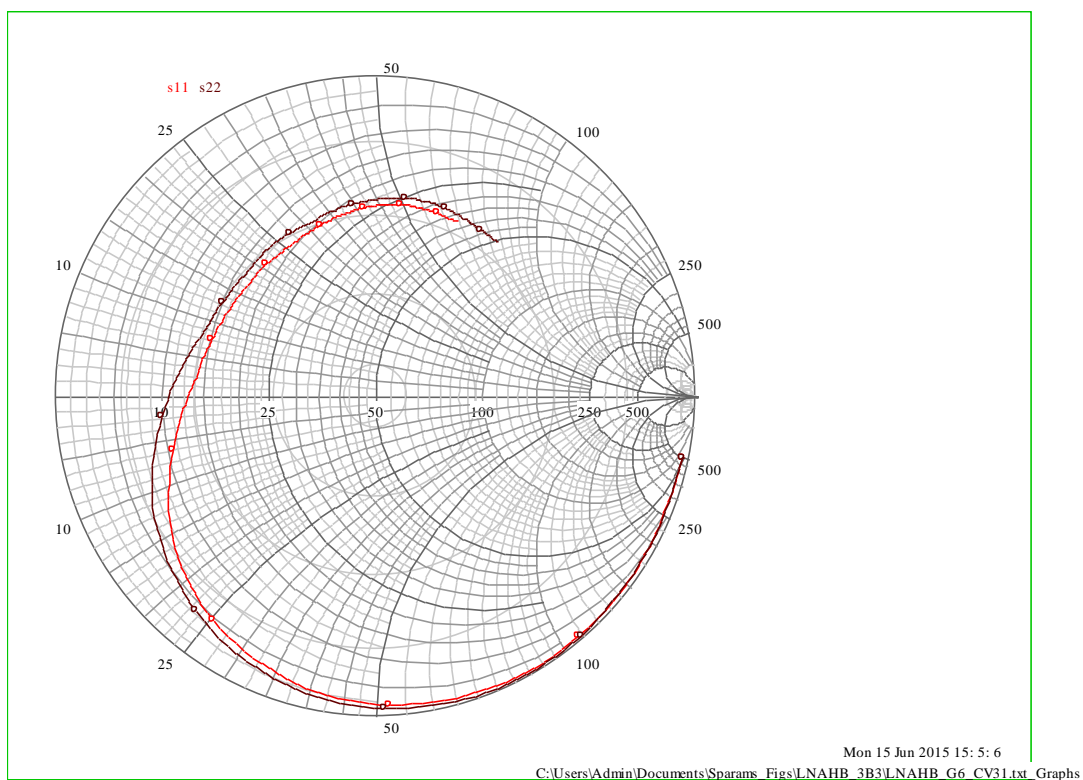


Figure 53 LNAHB Sample=3 Gain=6, Cap_Var =31

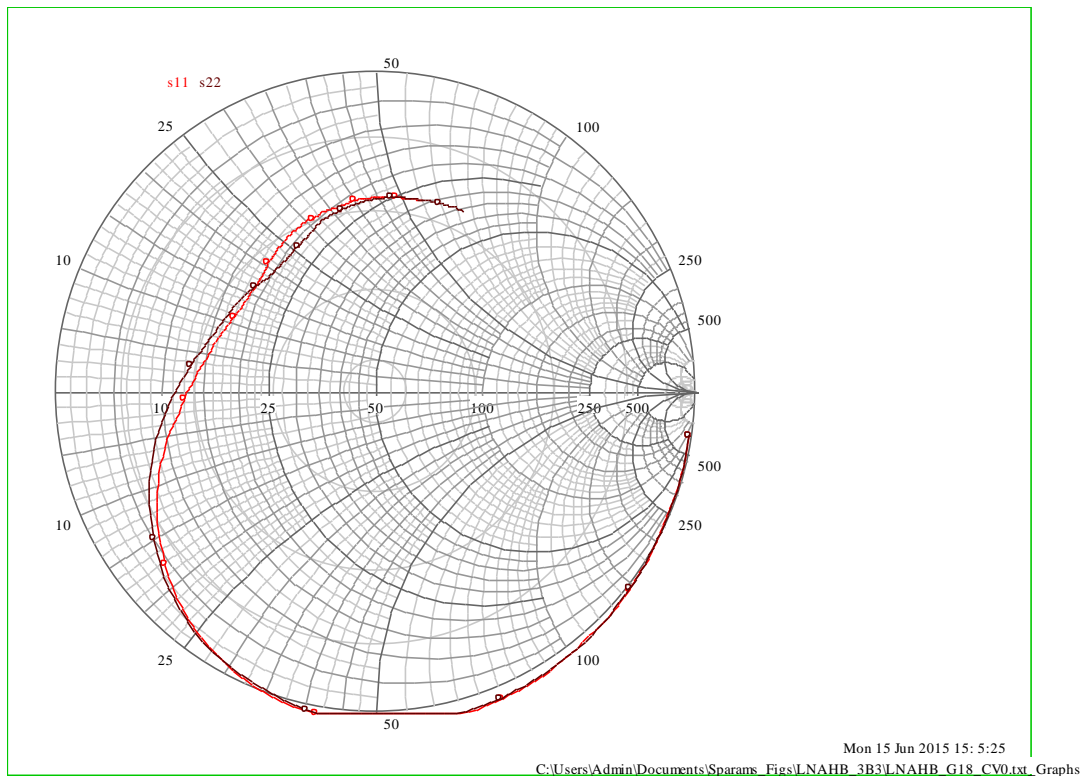


Figure 54 LNAHB Sample=3 Gain=18, Cap_Var =0

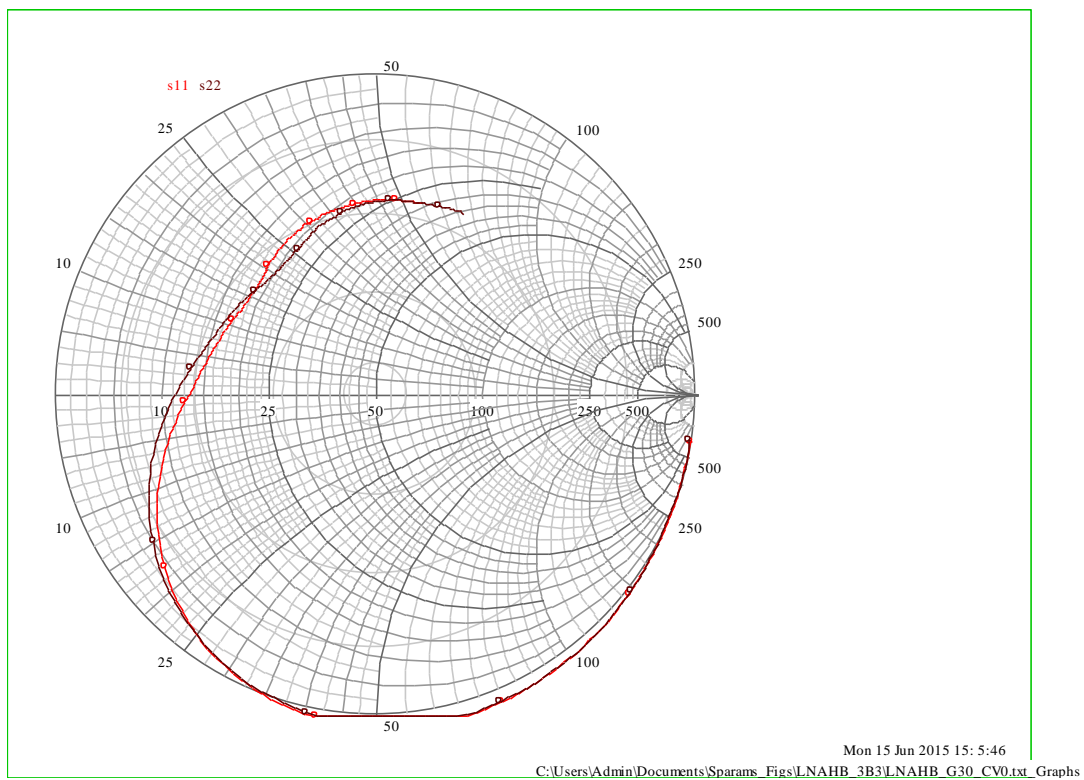


Figure 55 LNAHB Sample=3 Gain=31, Cap_Var =0

4.6 LNAL Channel A Sample 1

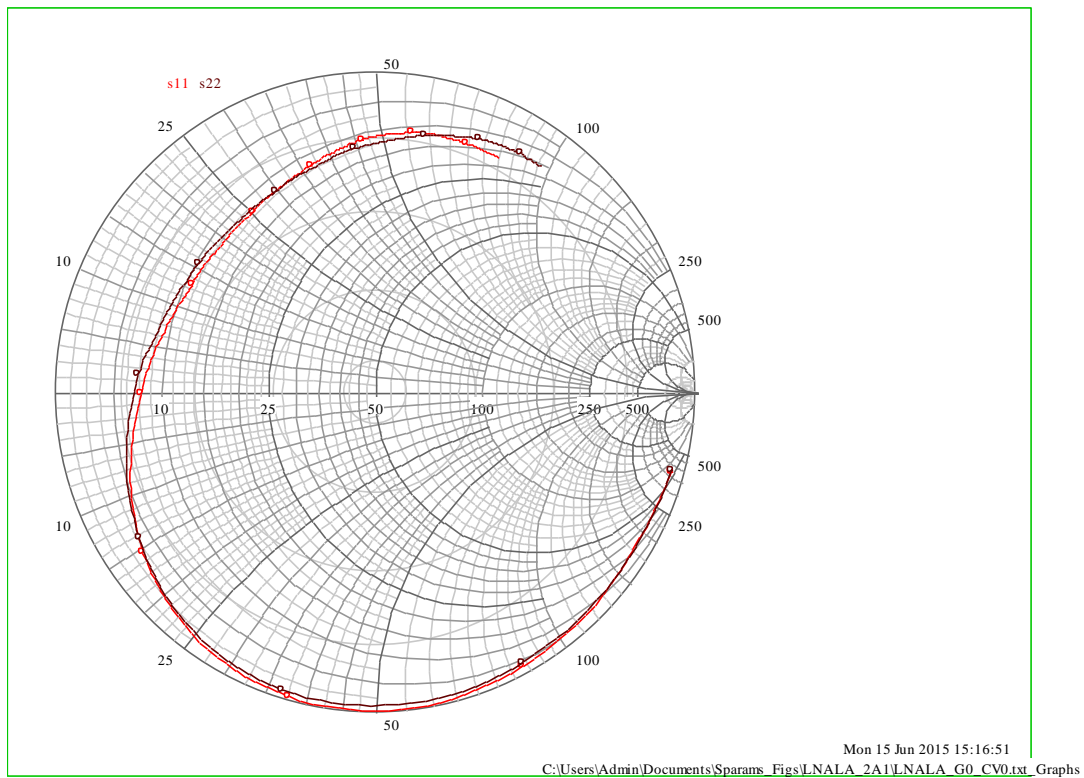


Figure 56 LNALA Sample=1 Gain=0, Cap_Var=0 Short=0

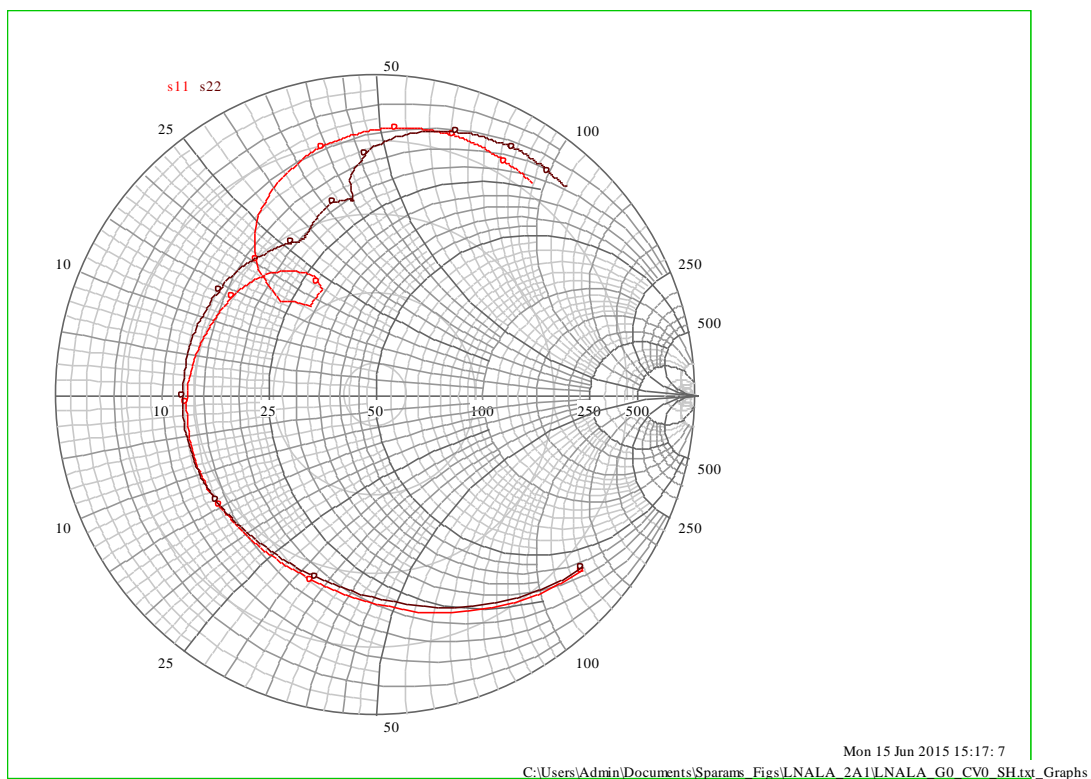


Figure 57 LNALA Sample=1 Gain=0, Cap_Var=0 Short=1

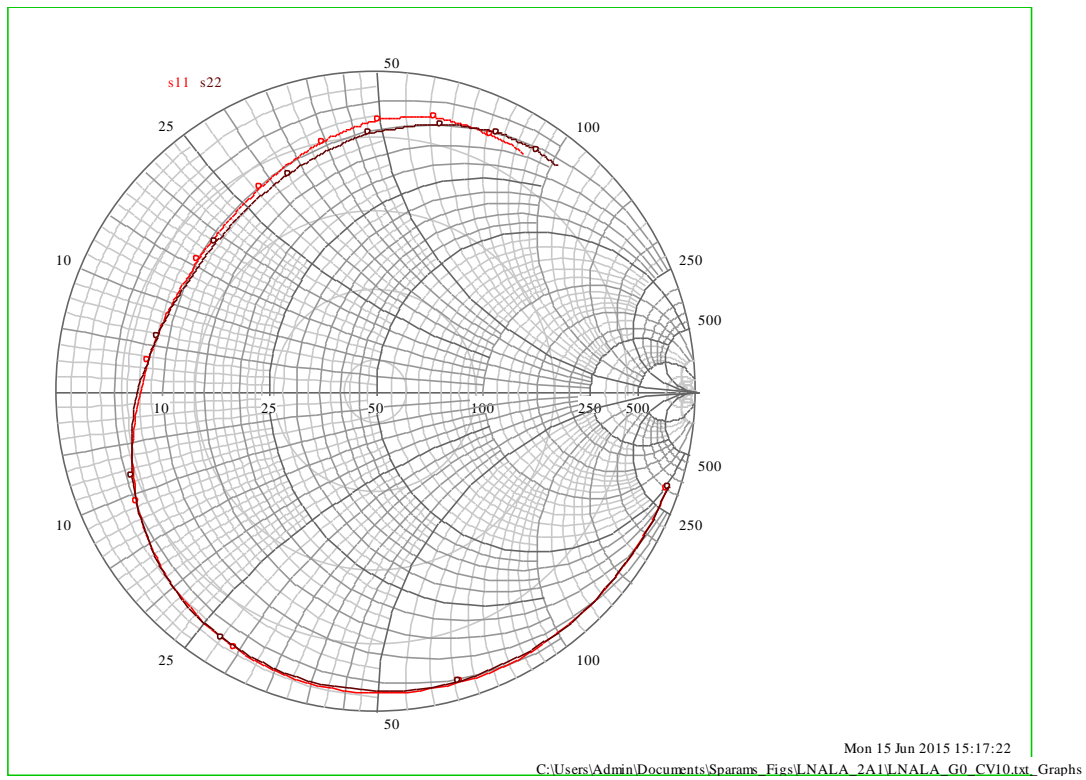


Figure 58 LNALA Sample=1 Gain=0, Cap_Var =10 Short=0

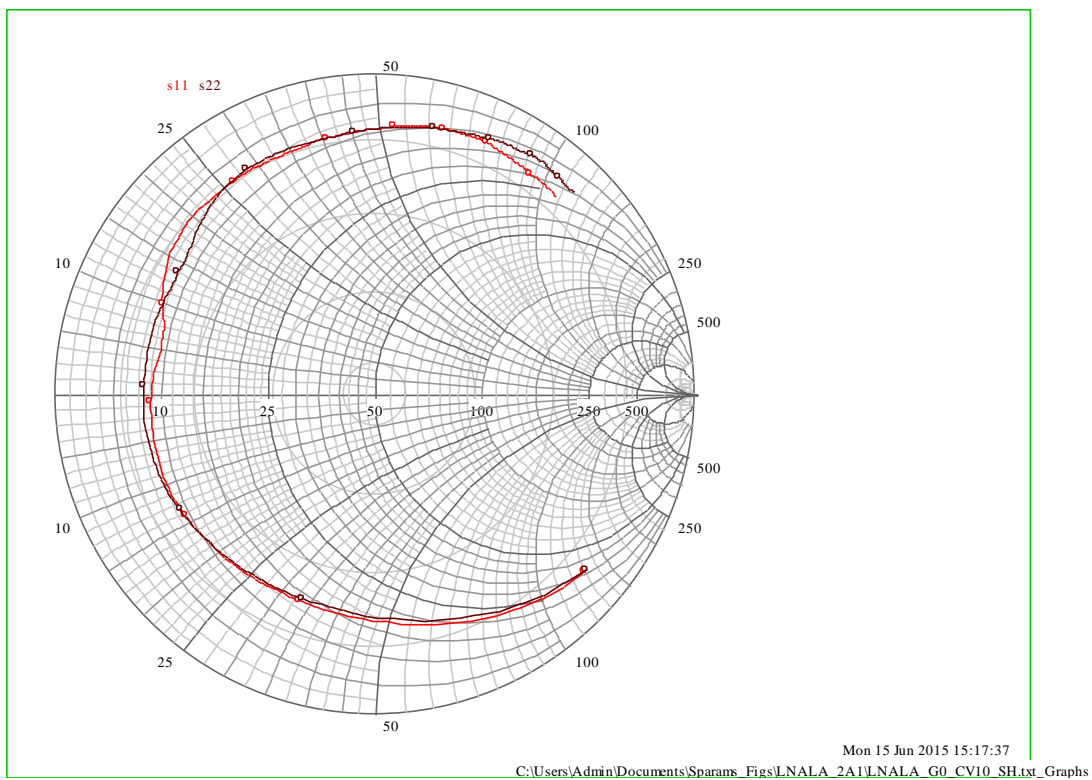


Figure 59 LNALA Sample=1 Gain=0, Cap_Var =10 Short=1

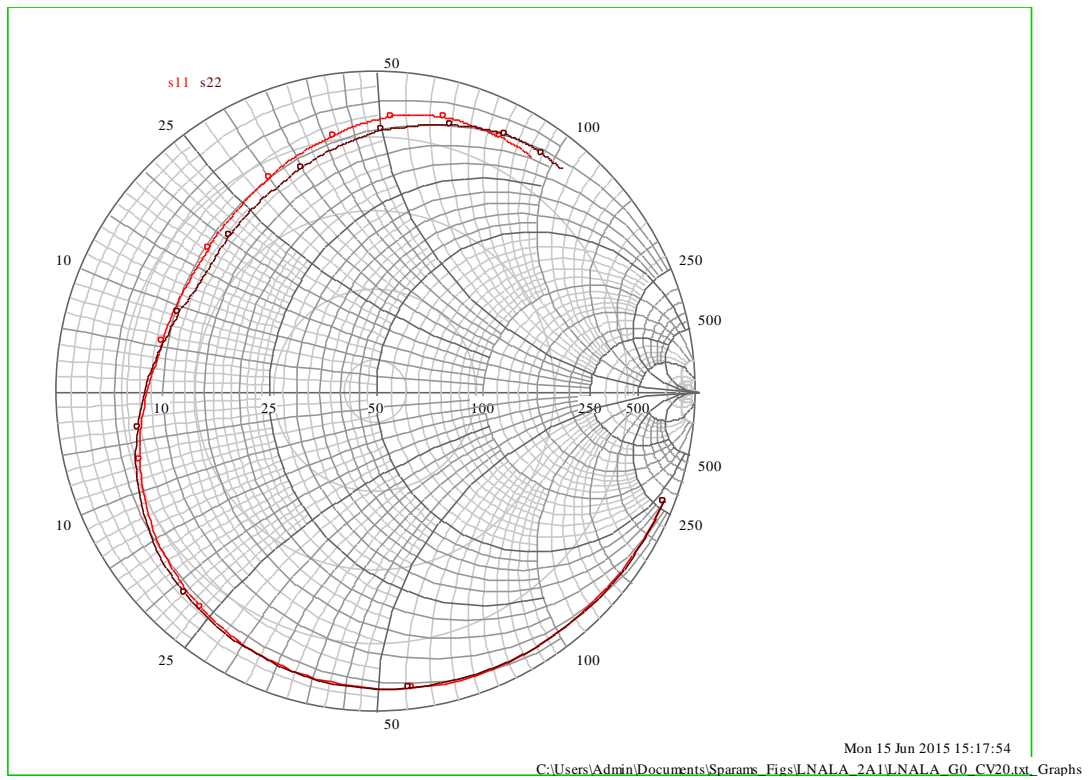


Figure 60 LNALA Sample=1 Gain=0, Cap_Var =20 Short=0

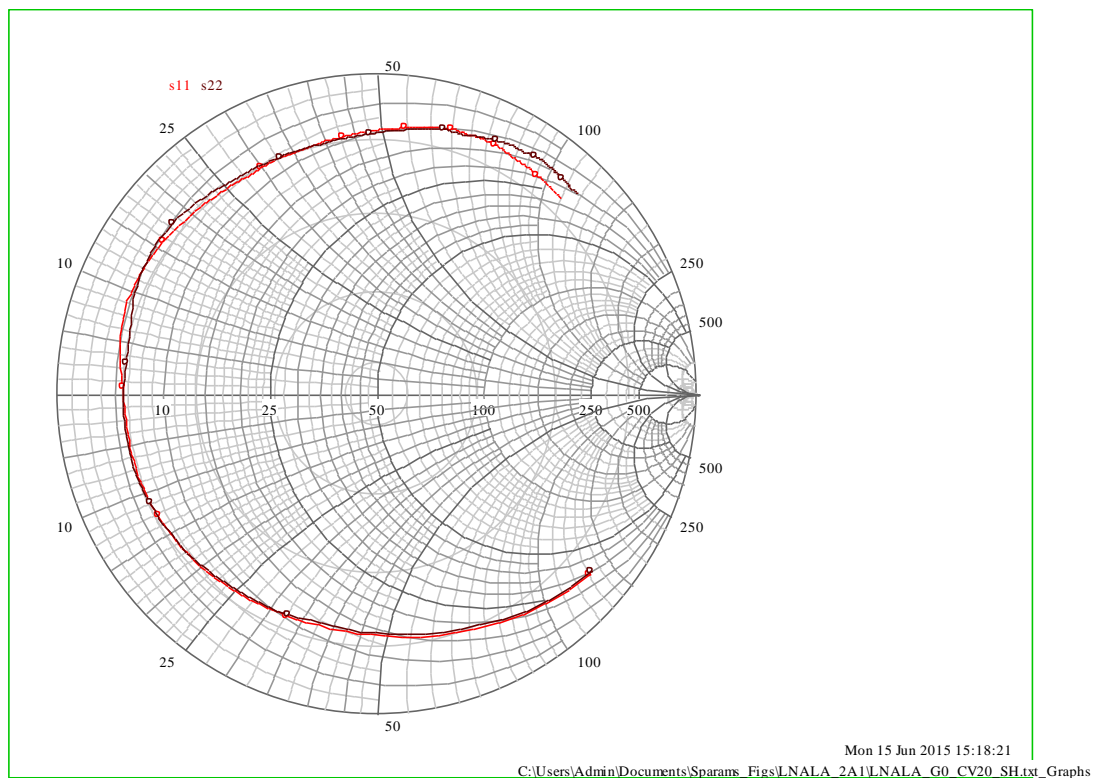


Figure 61 LNALA Sample=1 Gain=0, Cap_Var =20 Short=1

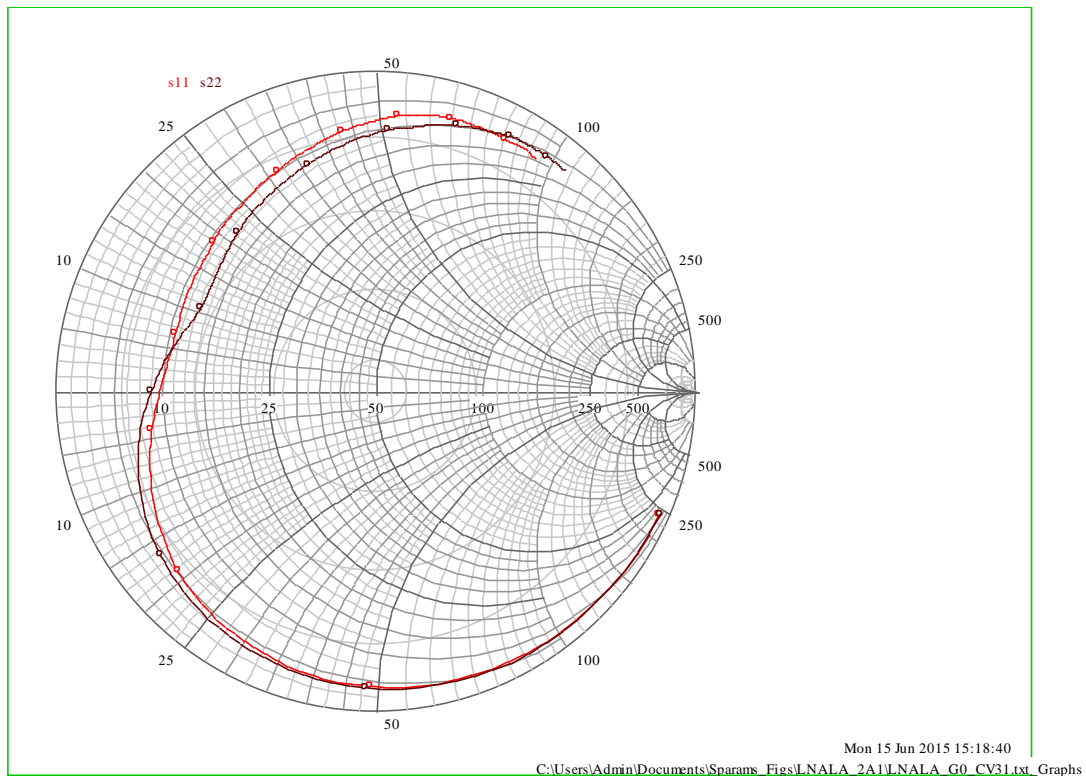


Figure 62 LNALA Sample=1 Gain=0, Cap_Var =31 Short=0

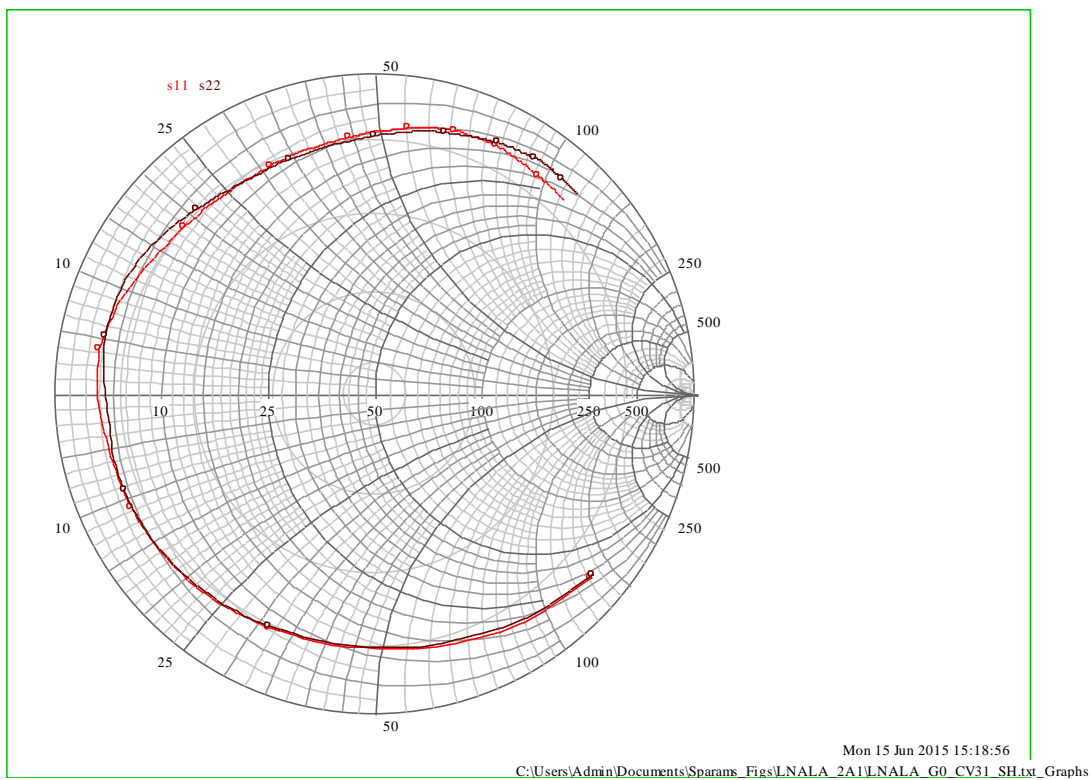


Figure 63 LNALA Sample=1 Gain=0, Cap_Var =31 Short=1

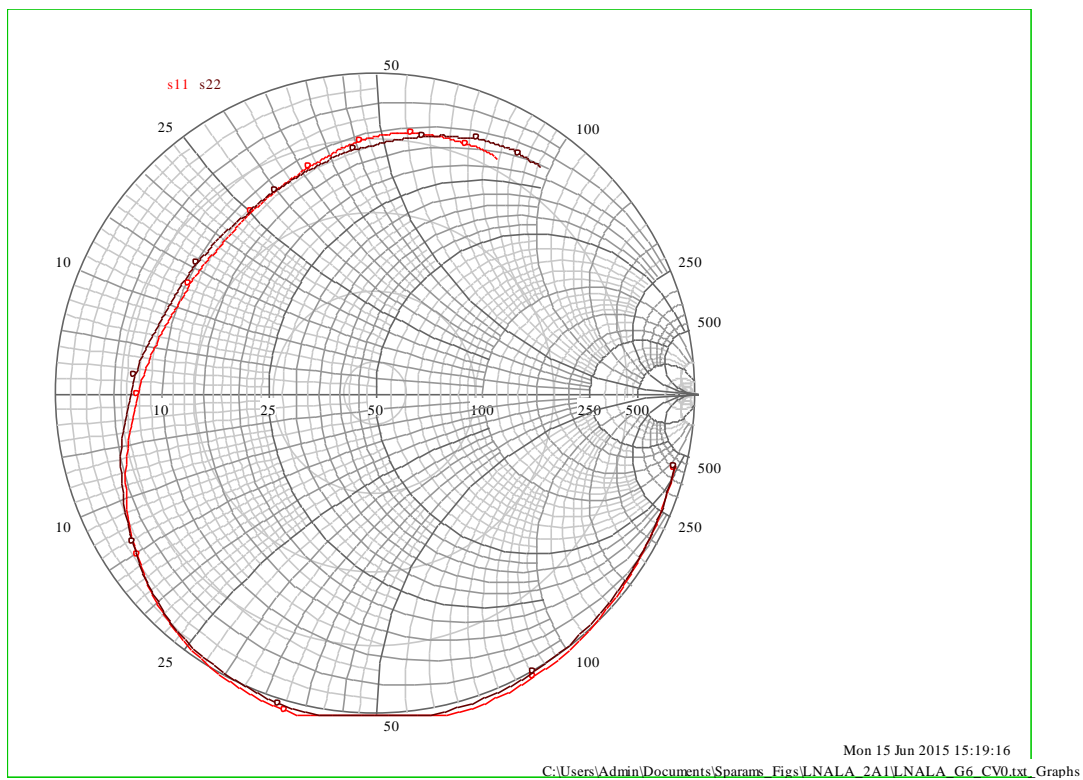


Figure 64 LNALA Sample=1 Gain=6, Cap_Var =0 Short=0

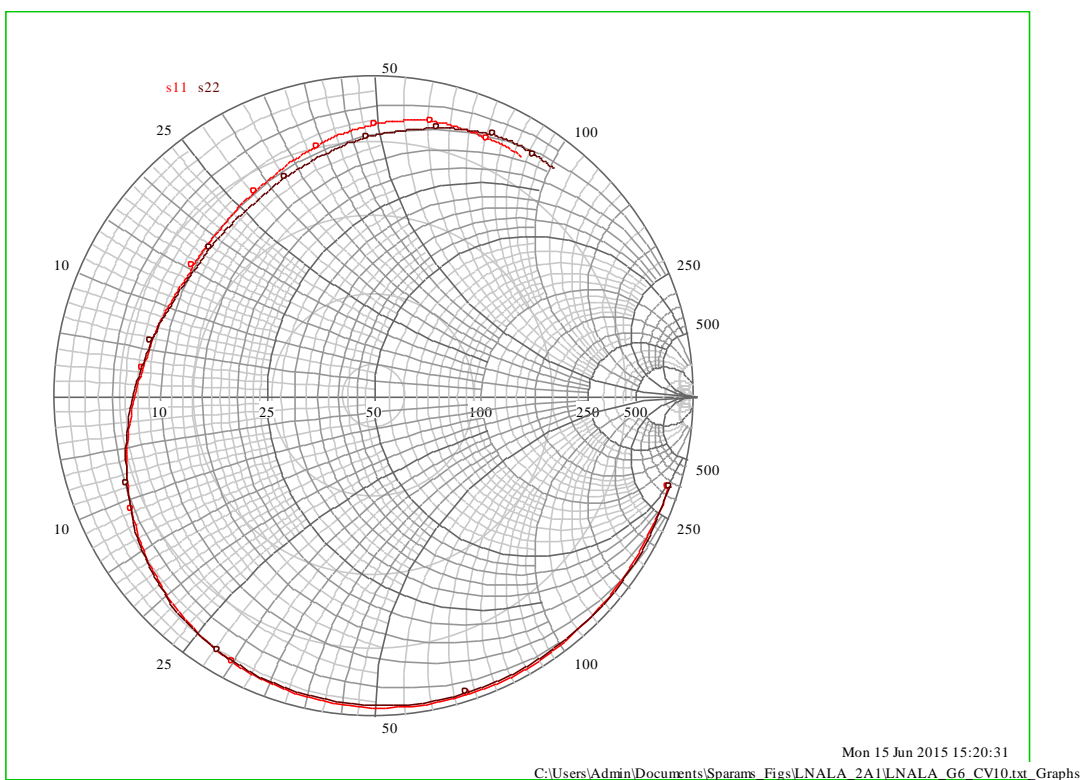


Figure 65 LNALA Sample=1 Gain=6, Cap_Var =10 Short=0

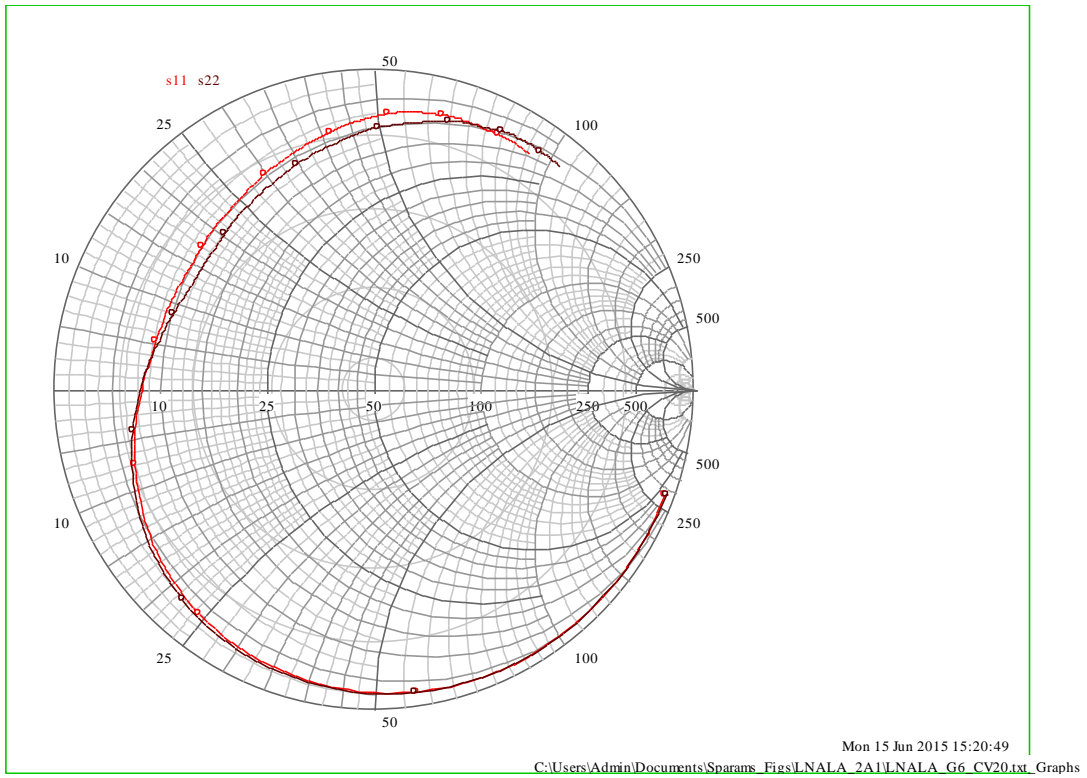


Figure 66 LNALA Sample=1 Gain=6, Cap_Var =20 Short=0

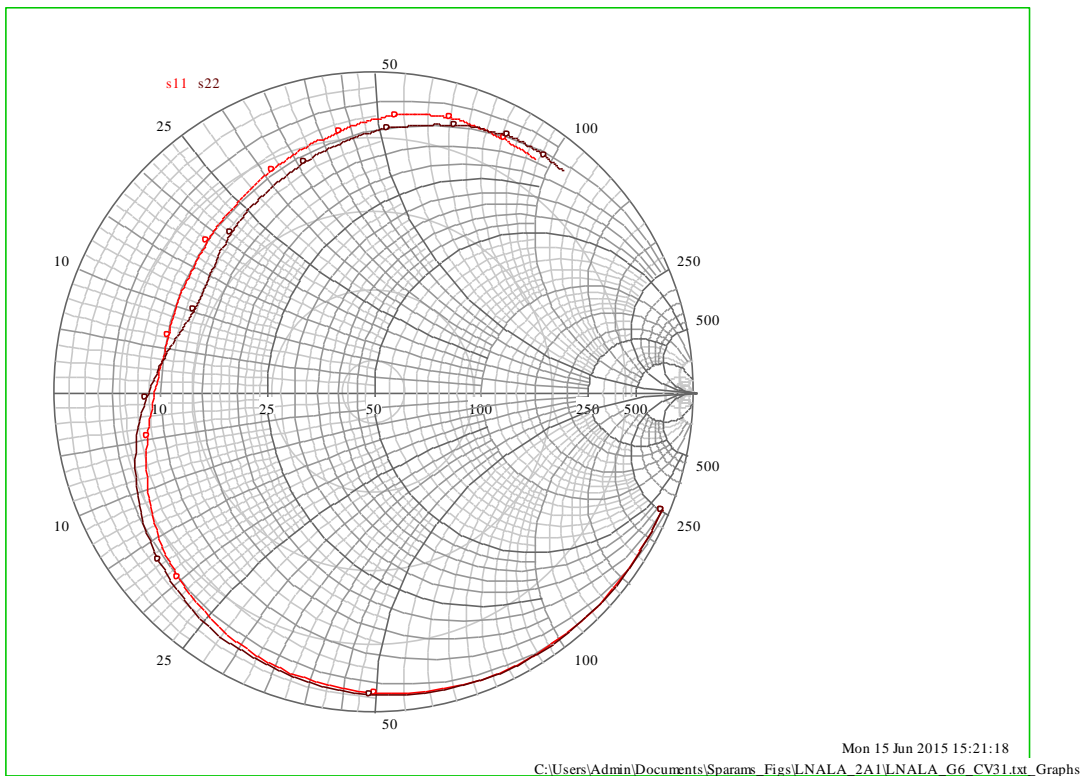


Figure 67 LNALA Sample=1 Gain=6, Cap_Var =31 Short=0

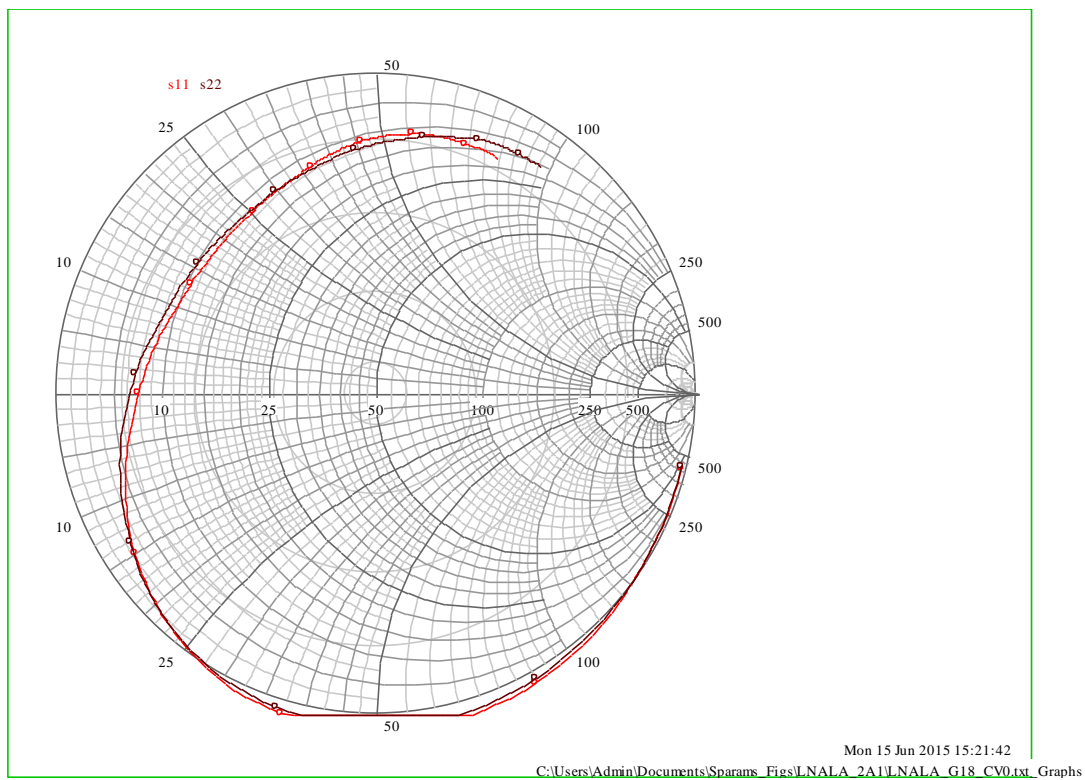


Figure 68 LNALA Sample=1 Gain=18, Cap_Var =0 Short=0

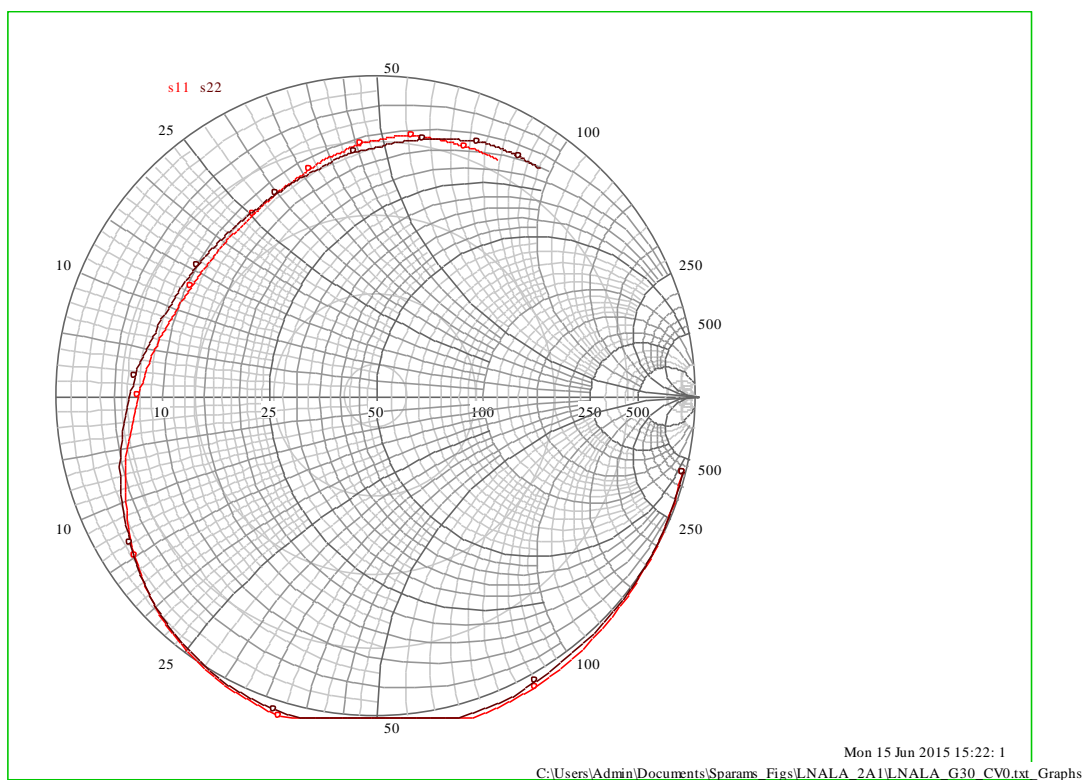


Figure 69 LNALA Sample=1 Gain=31, Cap_Var =0 Short=0

4.7 LNAL Channel A Sample 2

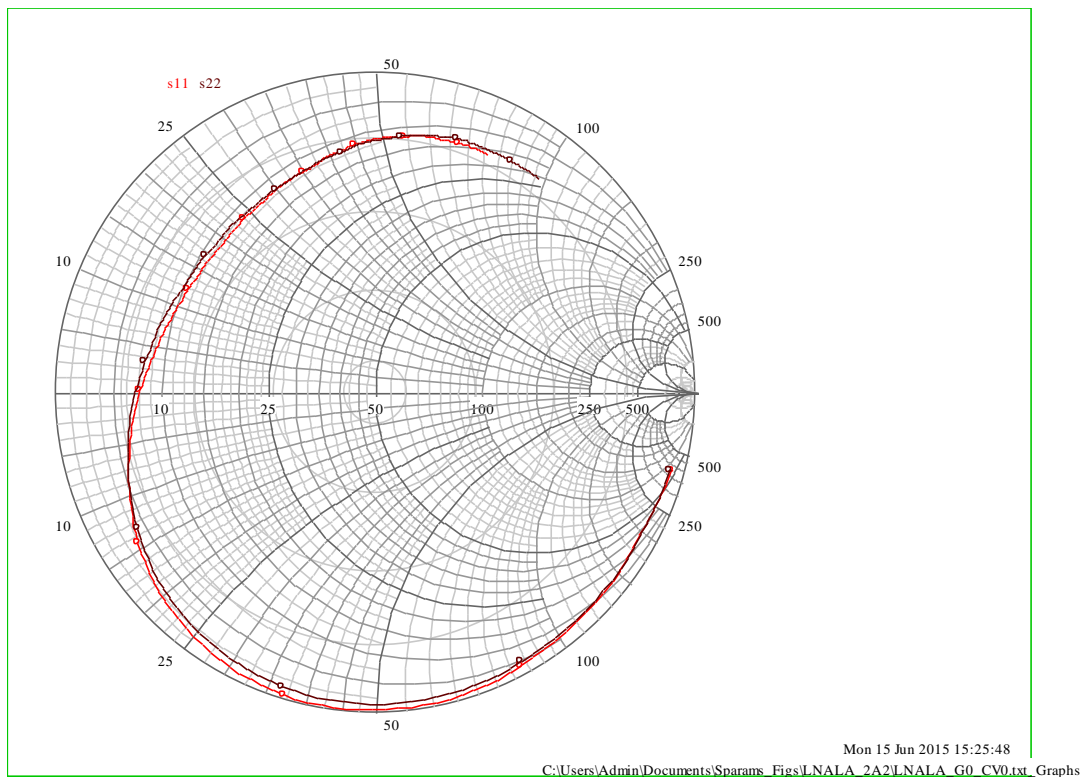


Figure 70 LNALA Sample=2 Gain=0, Cap_Var=0 Short=0

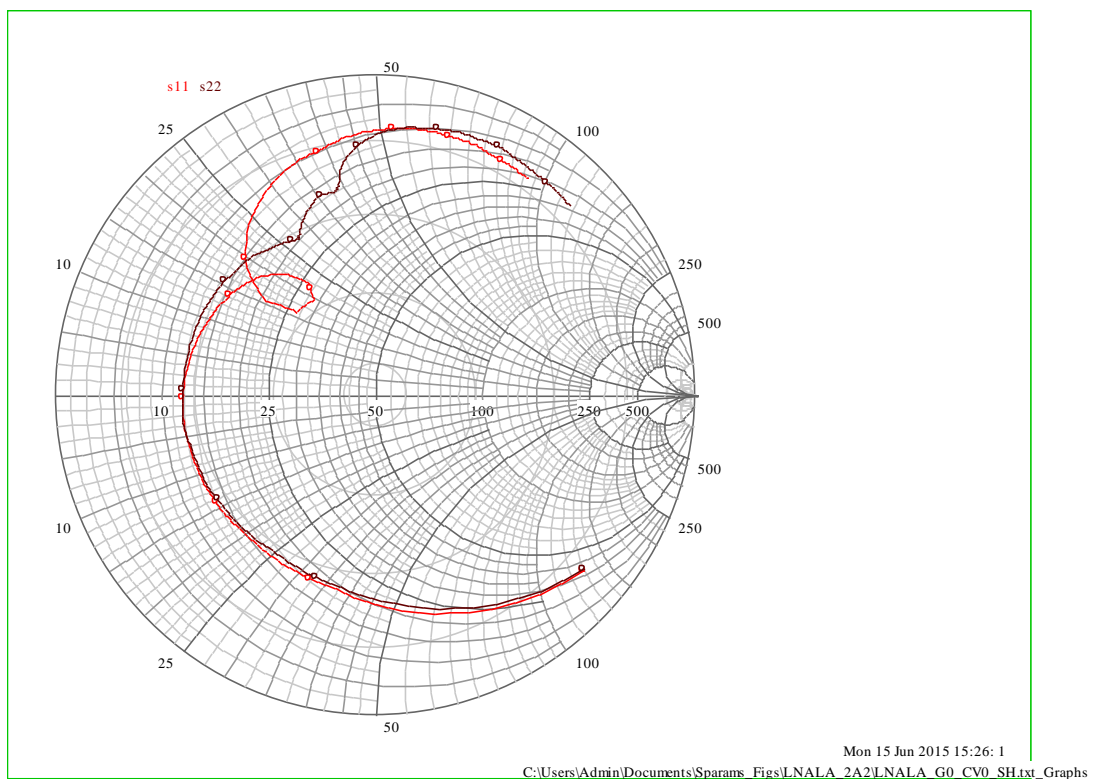


Figure 71 LNALA Sample=2 Gain=0, Cap_Var=0 Short=1

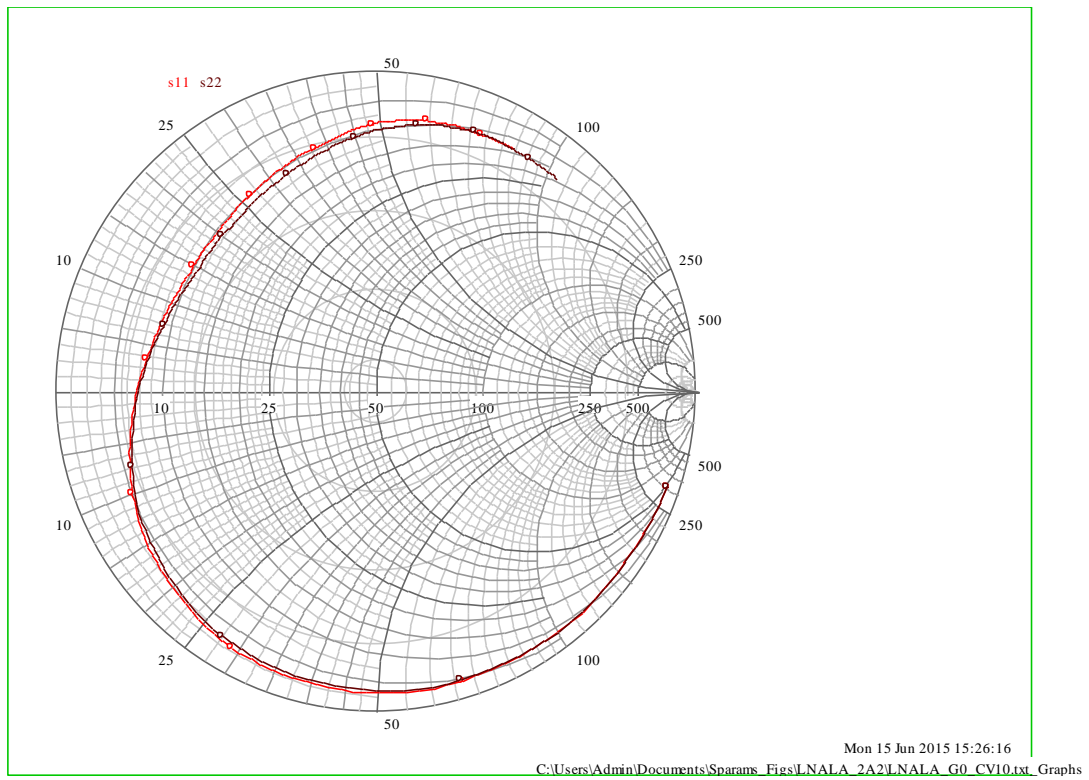


Figure 72 LNALA Sample=2 Gain=0, Cap_Var =10 Short=0

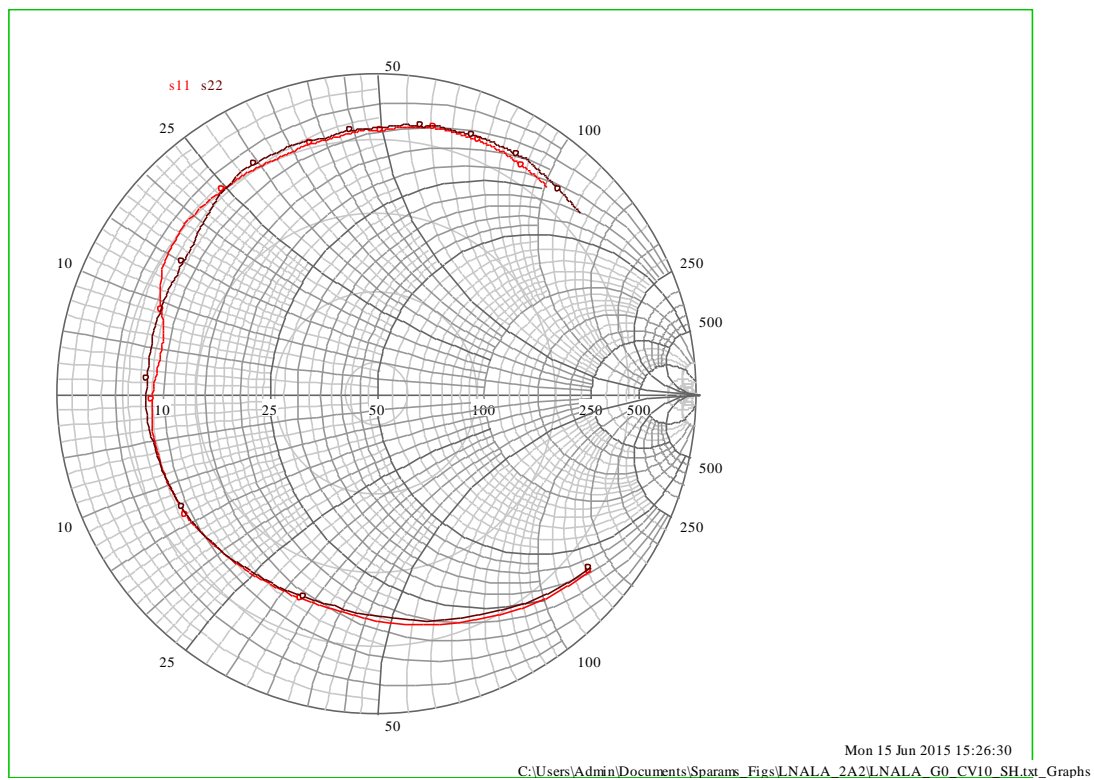


Figure 73 LNALA Sample=2 Gain=0, Cap_Var =10 Short=1

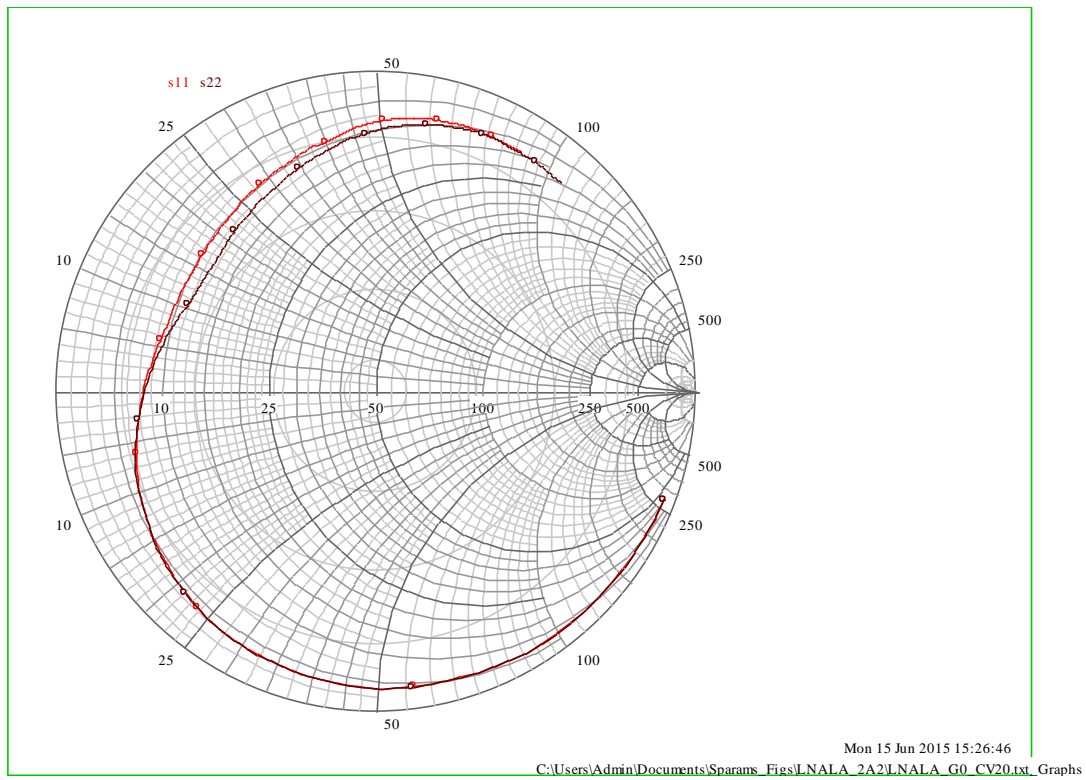


Figure 74 LNALA Sample=2 Gain=0, Cap_Var =20 Short=0

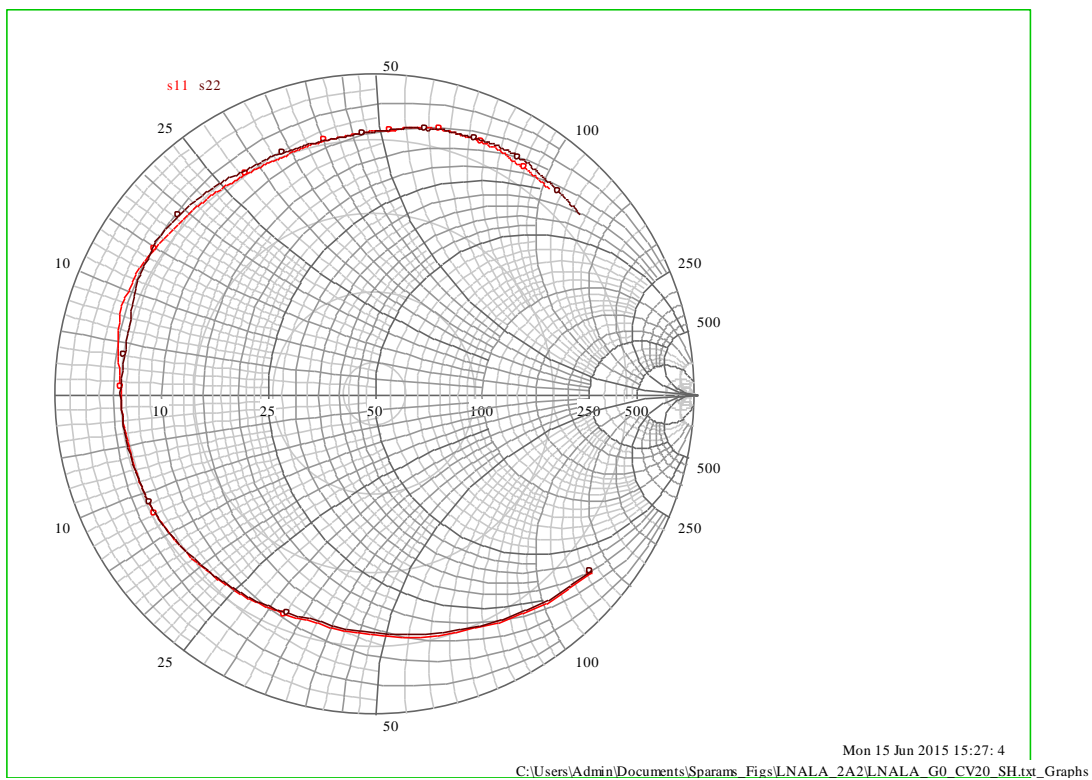


Figure 75 LNALA Sample=2 Gain=0, Cap_Var =20 Short=1

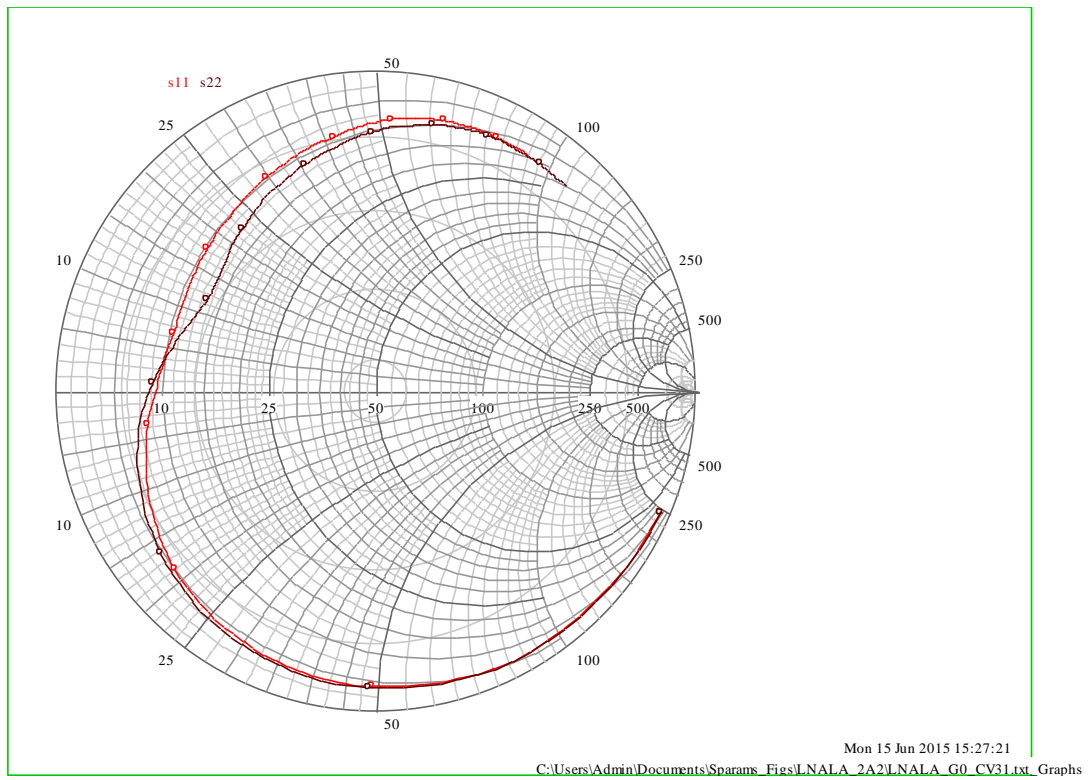


Figure 76 LNALA Sample=2 Gain=0, Cap_Var =31 Short=0

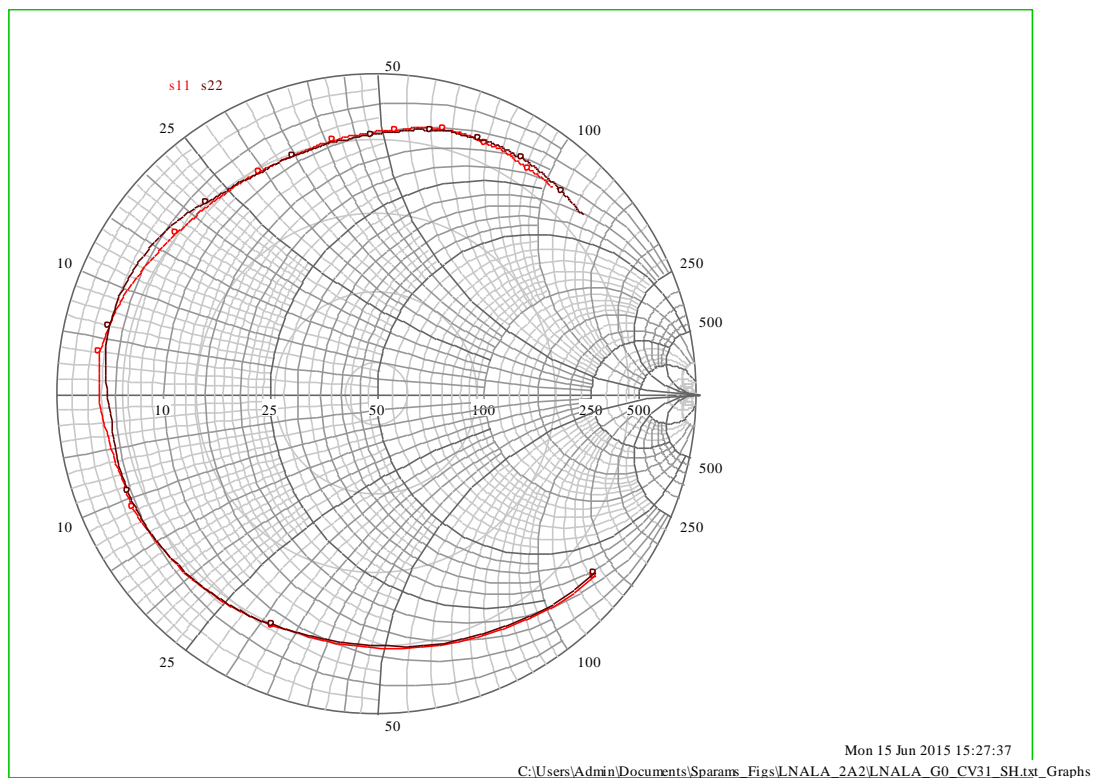


Figure 77 LNALA Sample=2 Gain=0, Cap_Var =31 Short=1

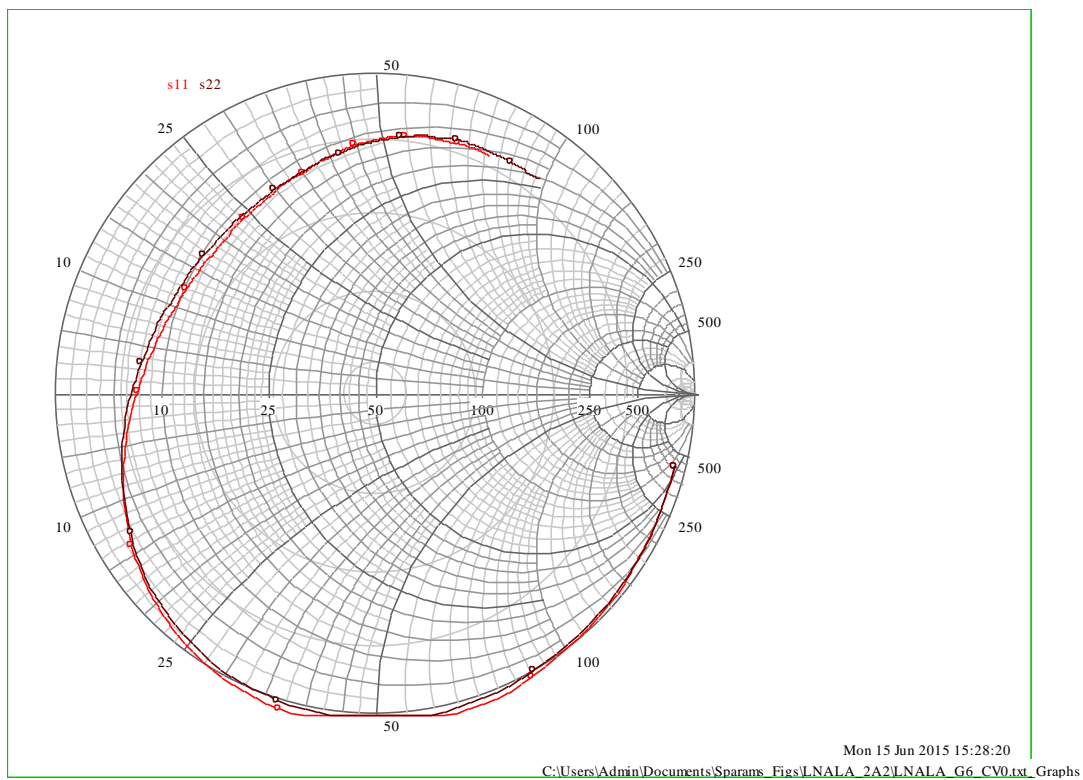


Figure 78 LNALA Sample=2 Gain=6, Cap_Var =0 Short=0

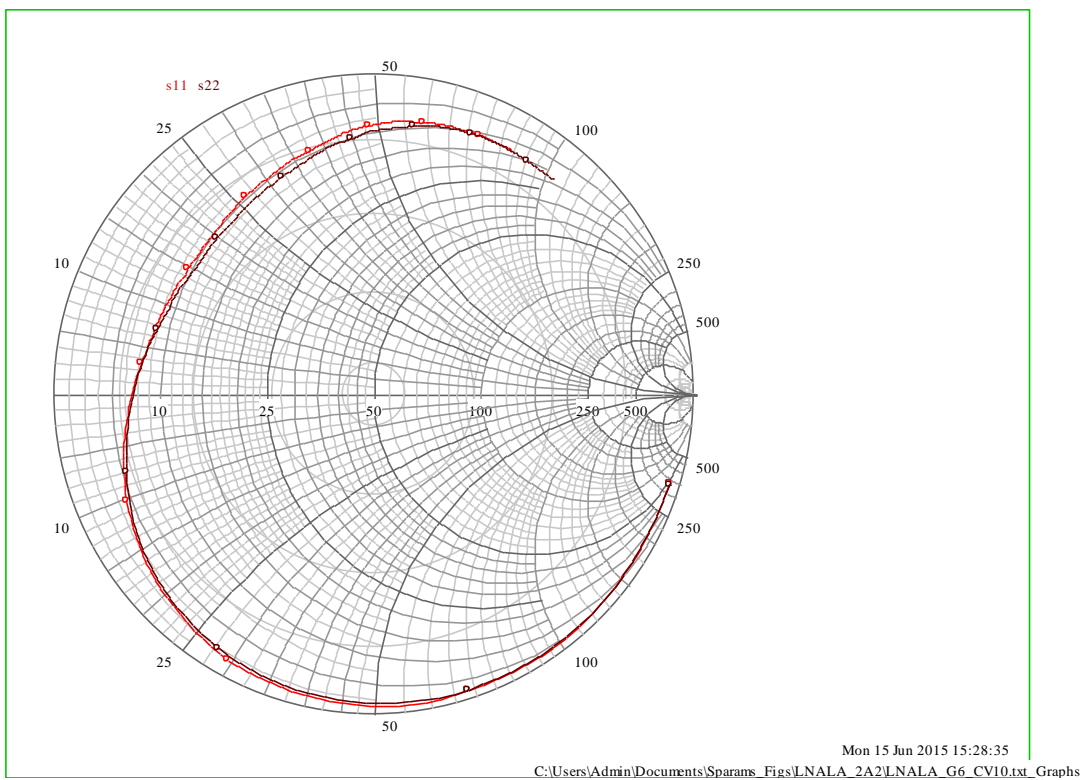


Figure 79 LNALA Sample=2 Gain=6, Cap_Var =10 Short=0

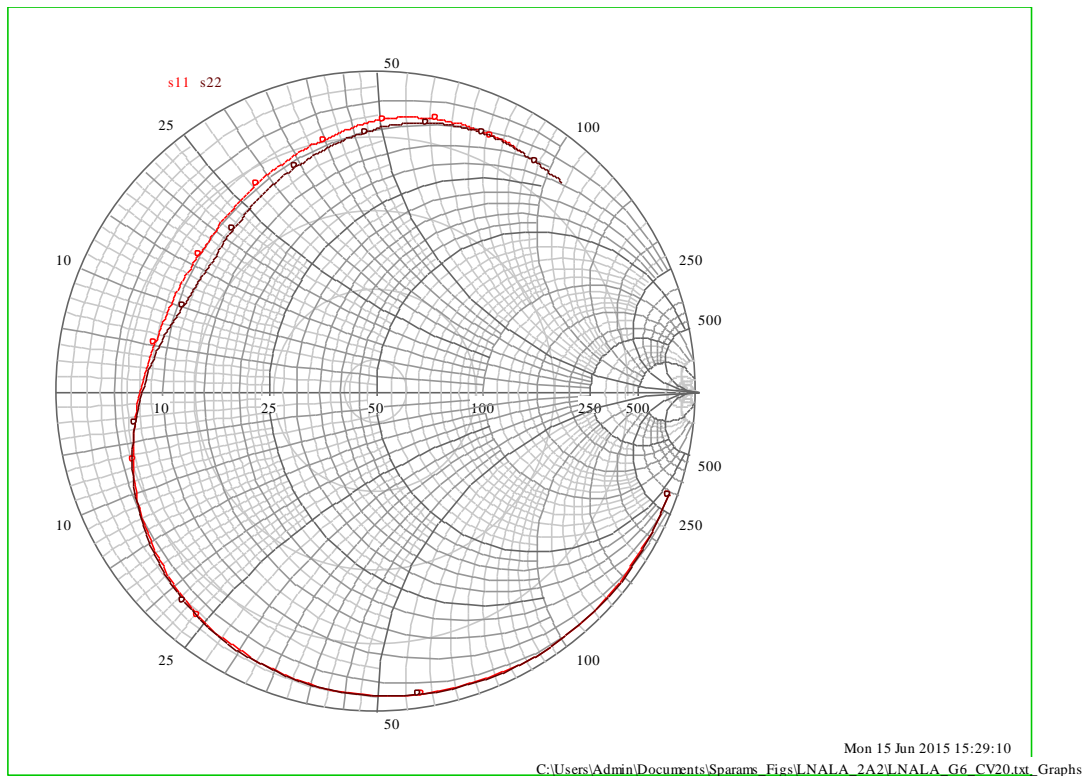


Figure 80 LNALA Sample=2 Gain=6, Cap_Var =20 Short=0

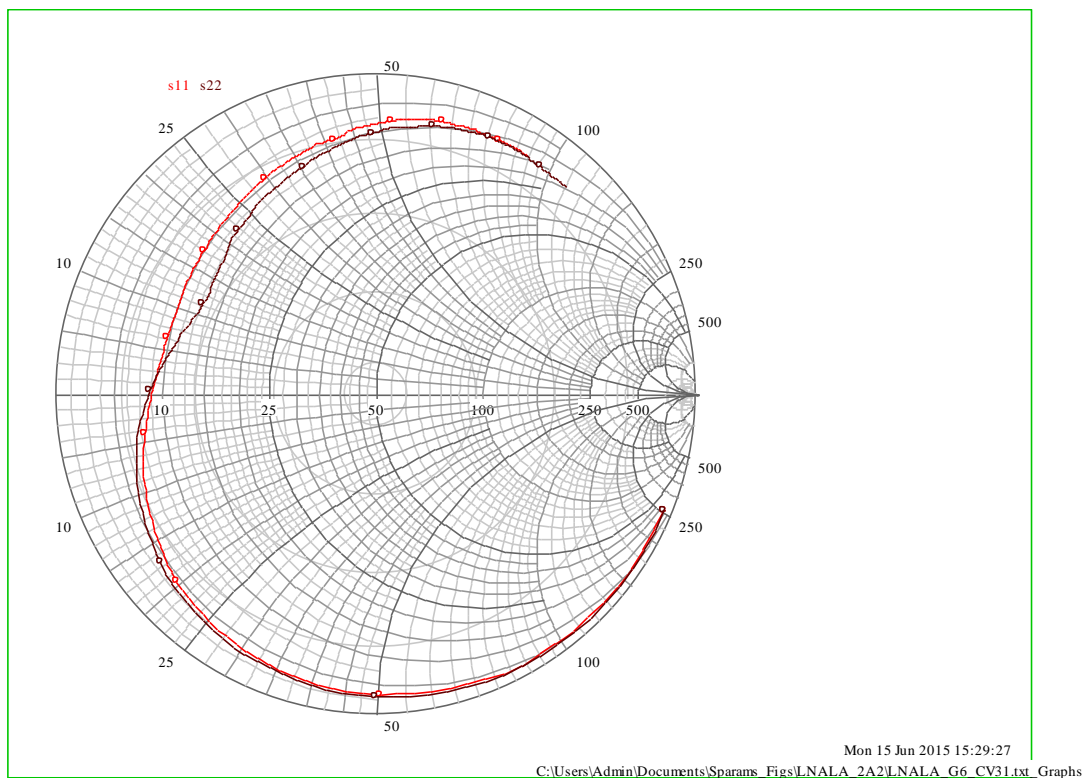


Figure 81 LNALA Sample=2 Gain=6, Cap_Var =31 Short=0

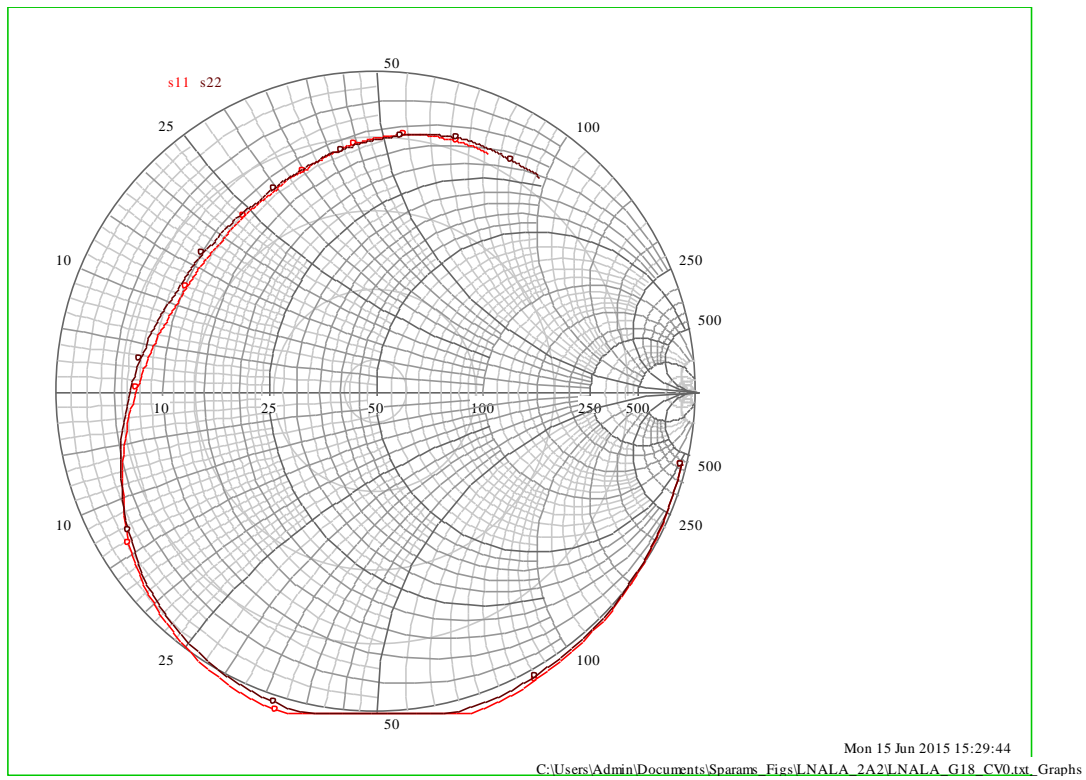


Figure 82 LNALA Sample=2 Gain=18, Cap_Var =0 Short=0

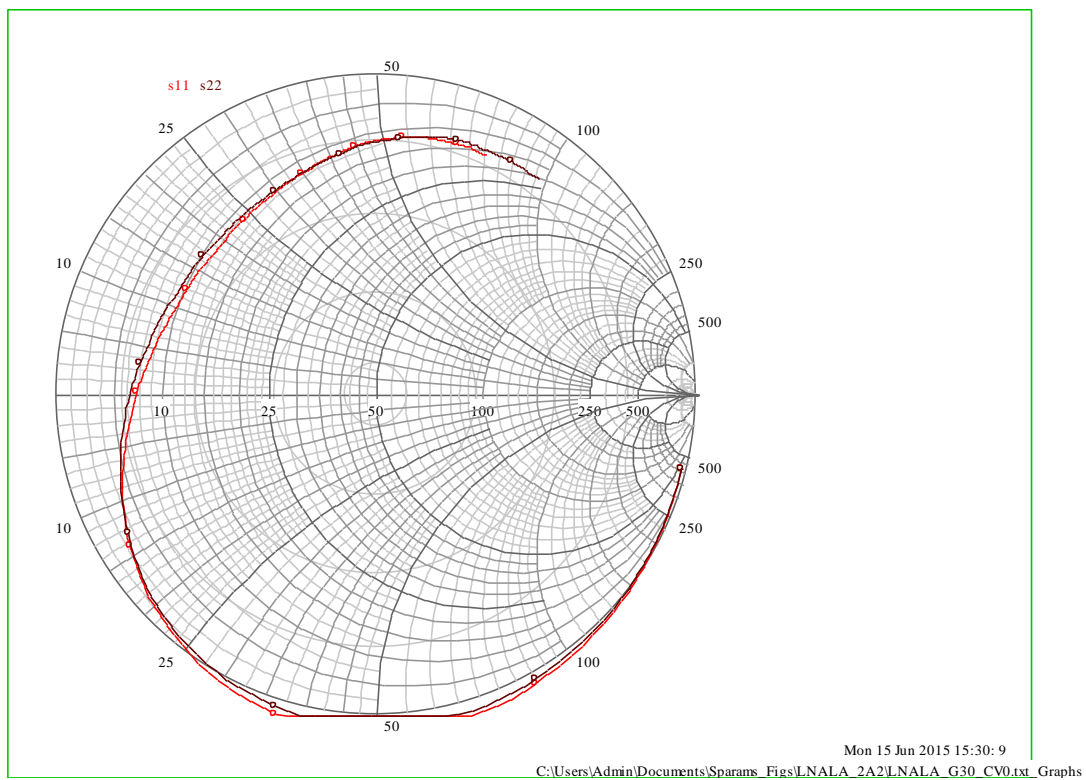


Figure 83 LNALA Sample=2 Gain=31, Cap_Var =0 Short=0

4.8 LNAL Channel A Sample 3

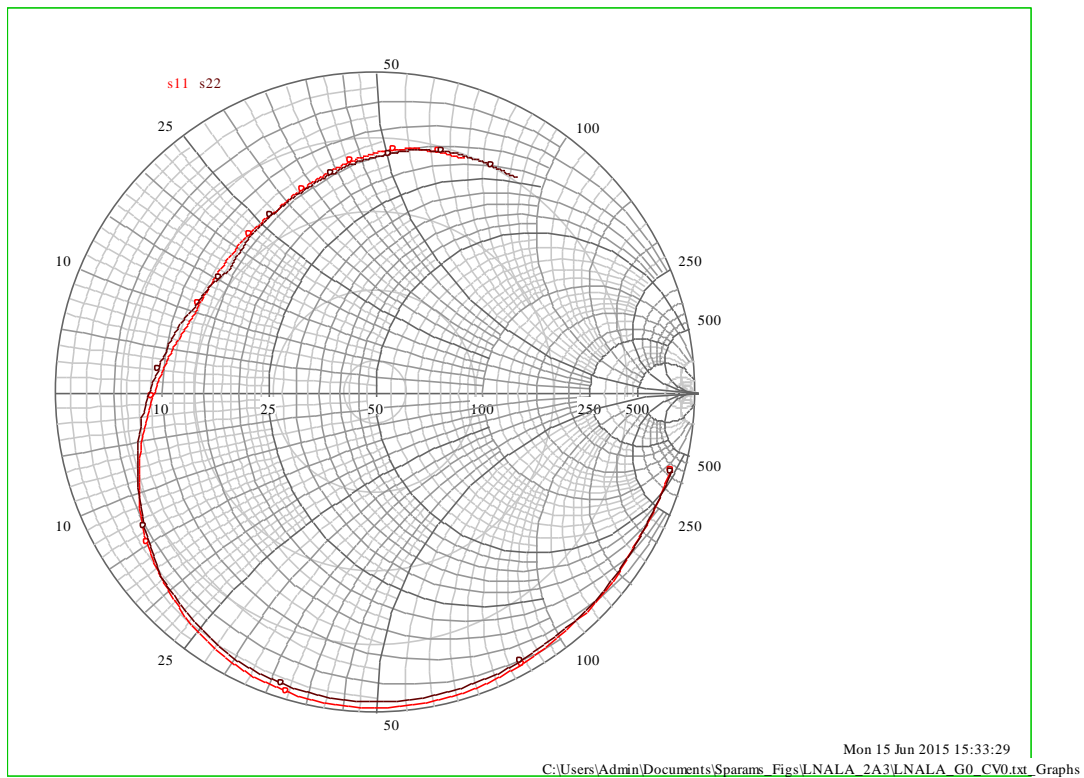


Figure 84 LNALA Sample=3 Gain=0, Cap_Var=0 Short=0

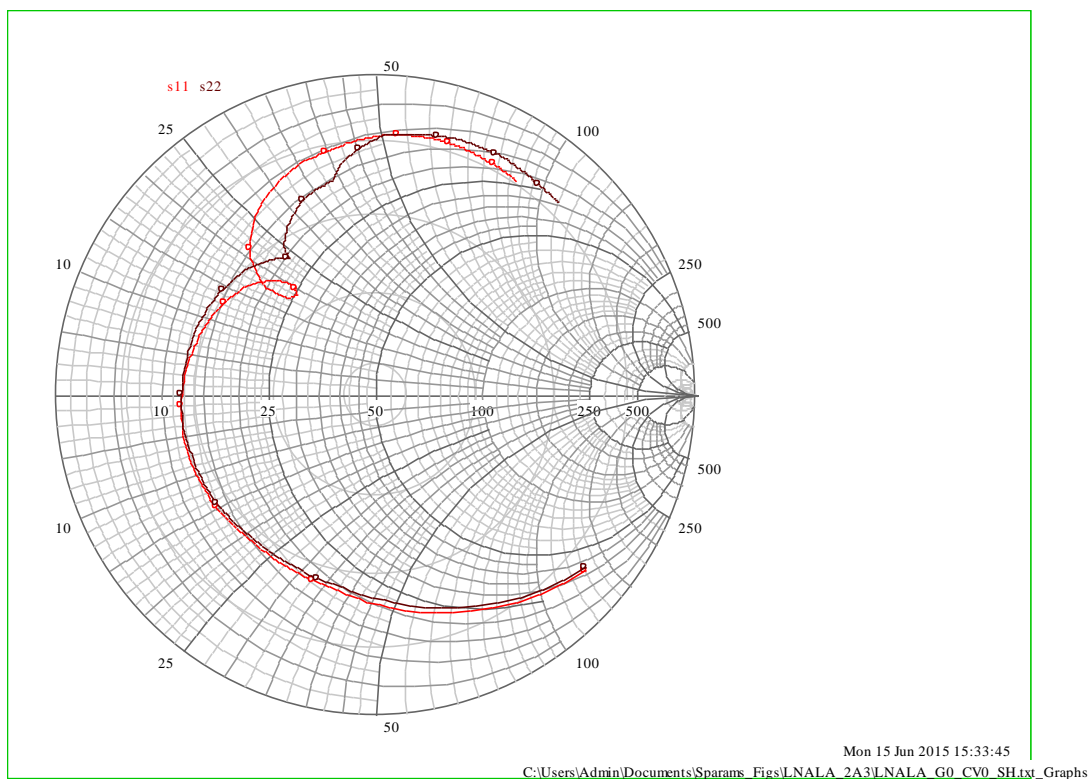


Figure 85 LNALA Sample=3 Gain=0, Cap_Var=0 Short=1

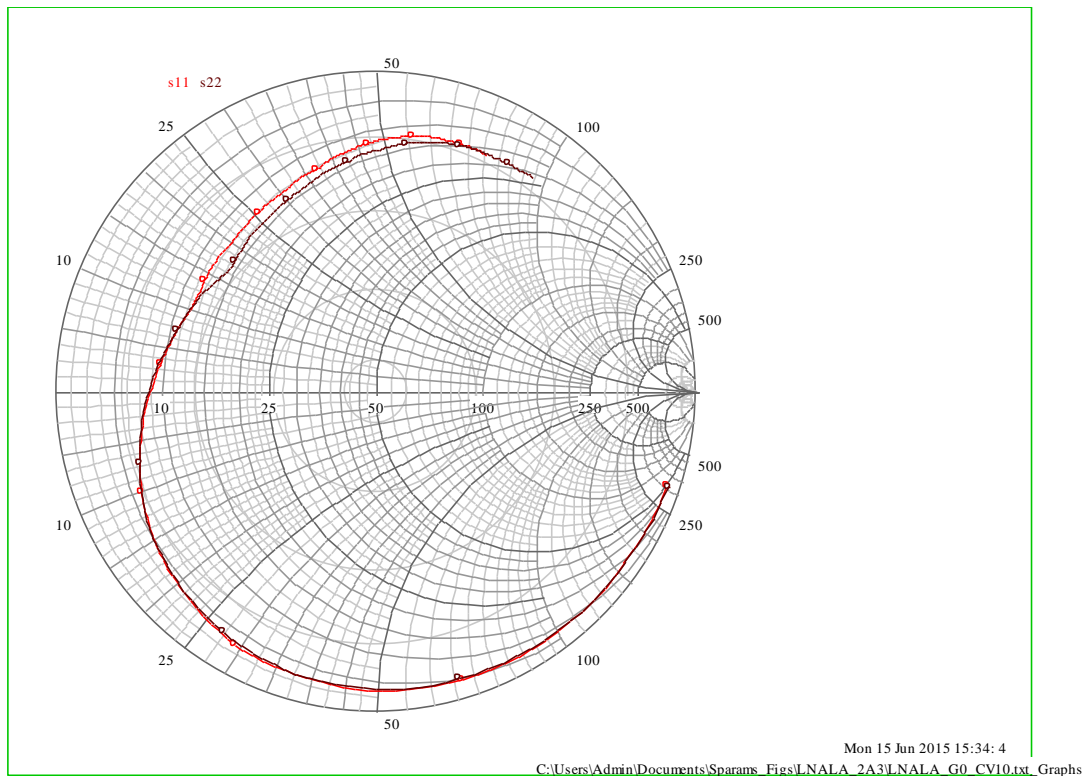


Figure 86 LNALA Sample=3 Gain=0, Cap_Var =10 Short=0

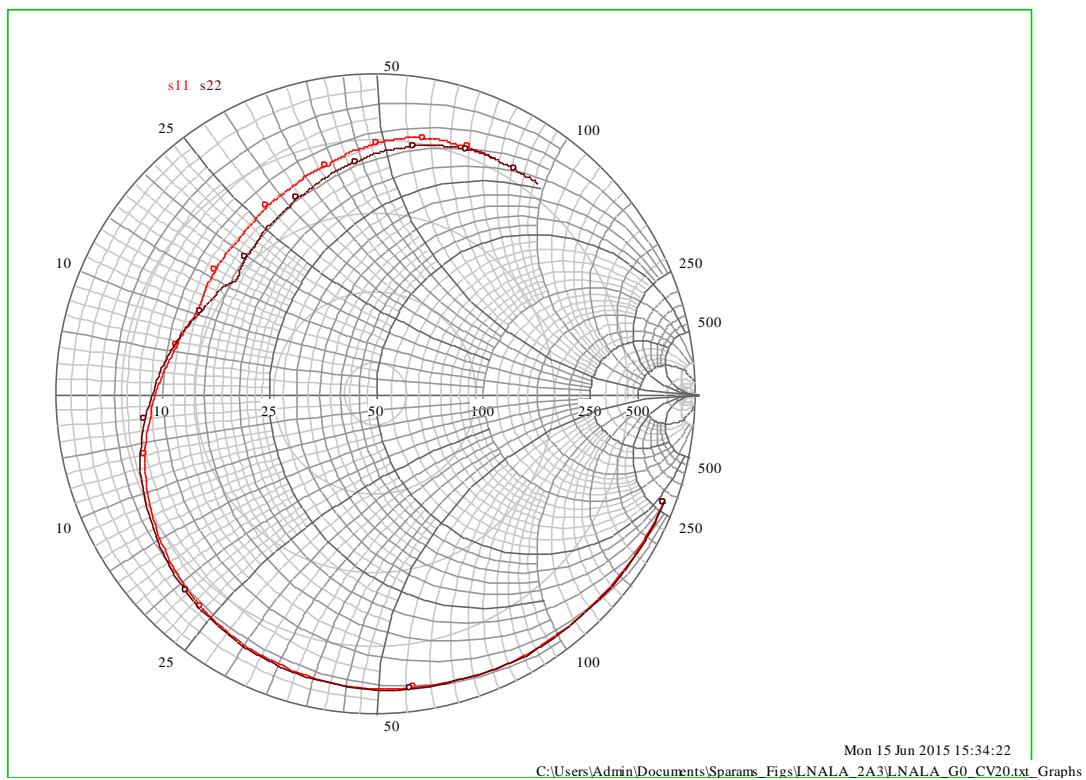
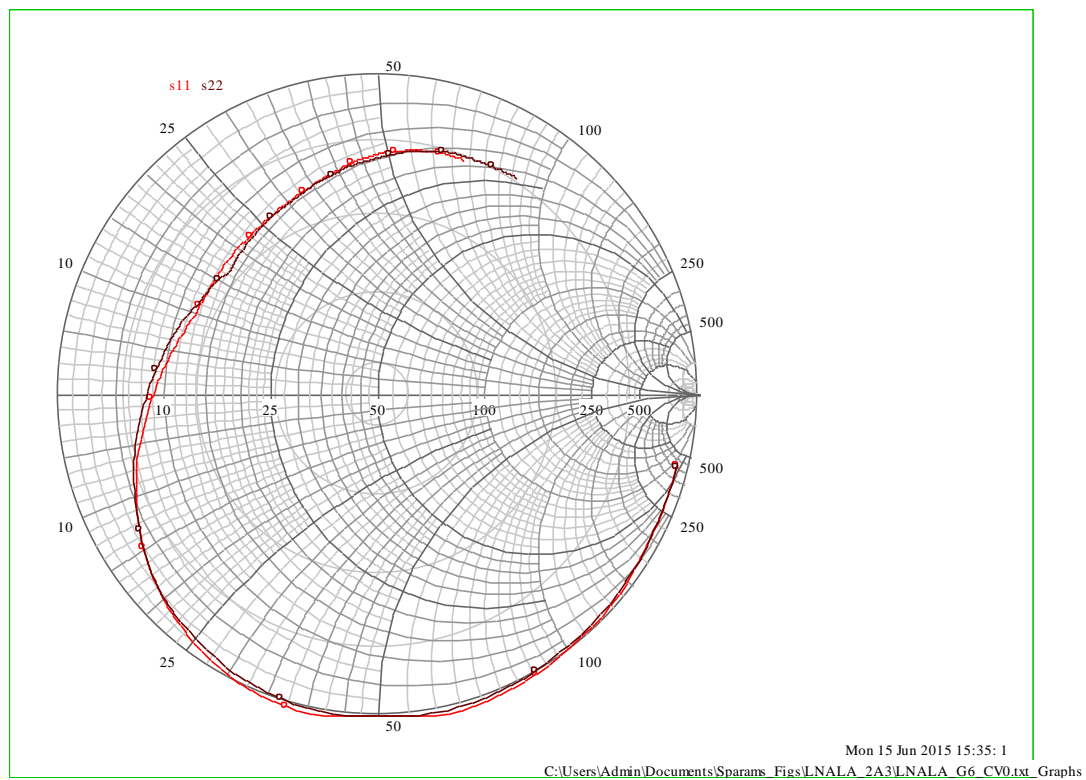
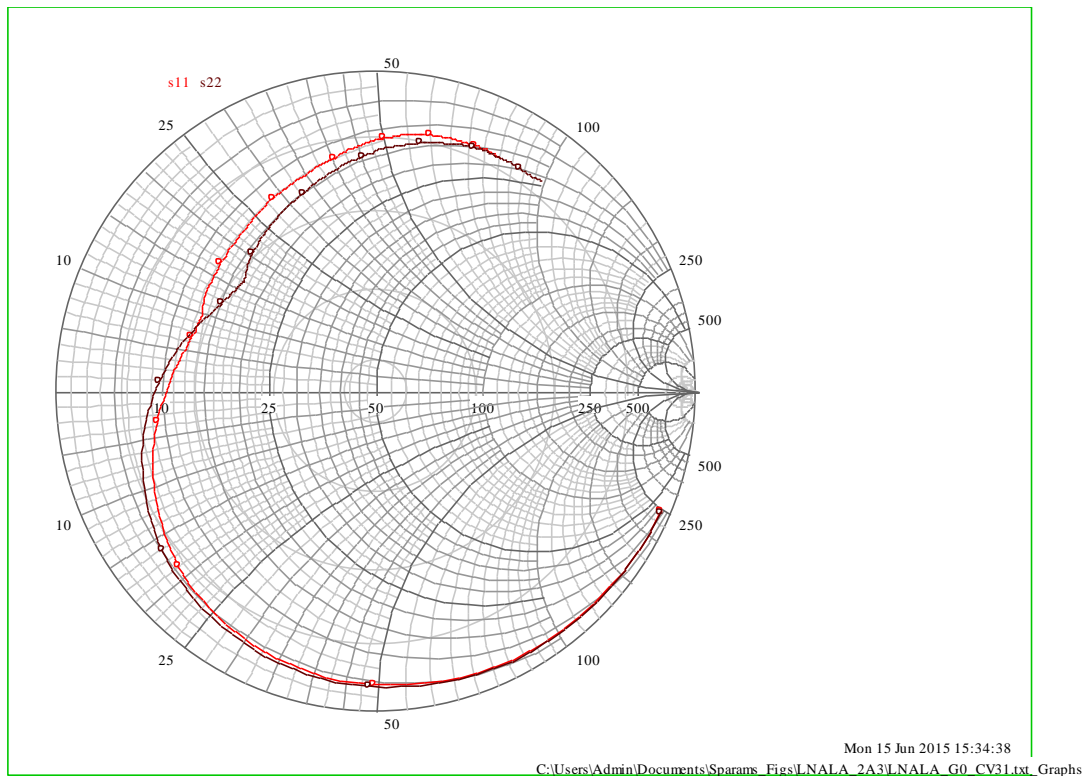


Figure 87 LNALA Sample=3 Gain=0, Cap_Var =20 Short=0



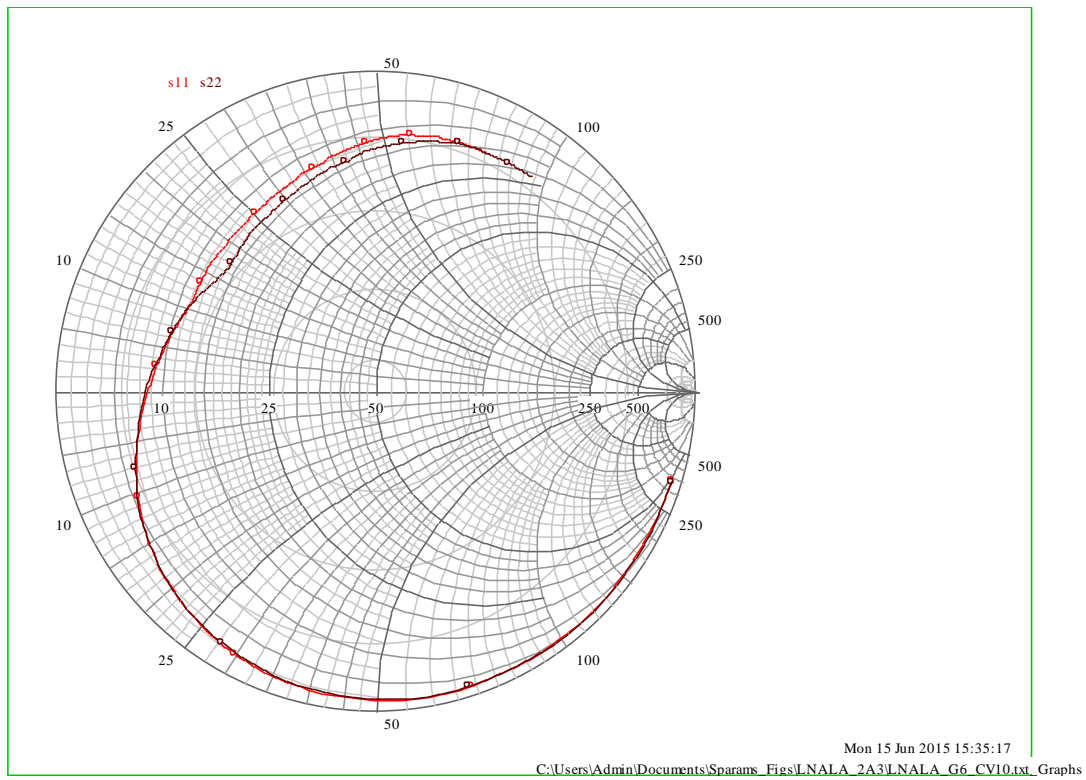


Figure 90 LNALA Sample=3 Gain=6, Cap_Var =10 Short=0

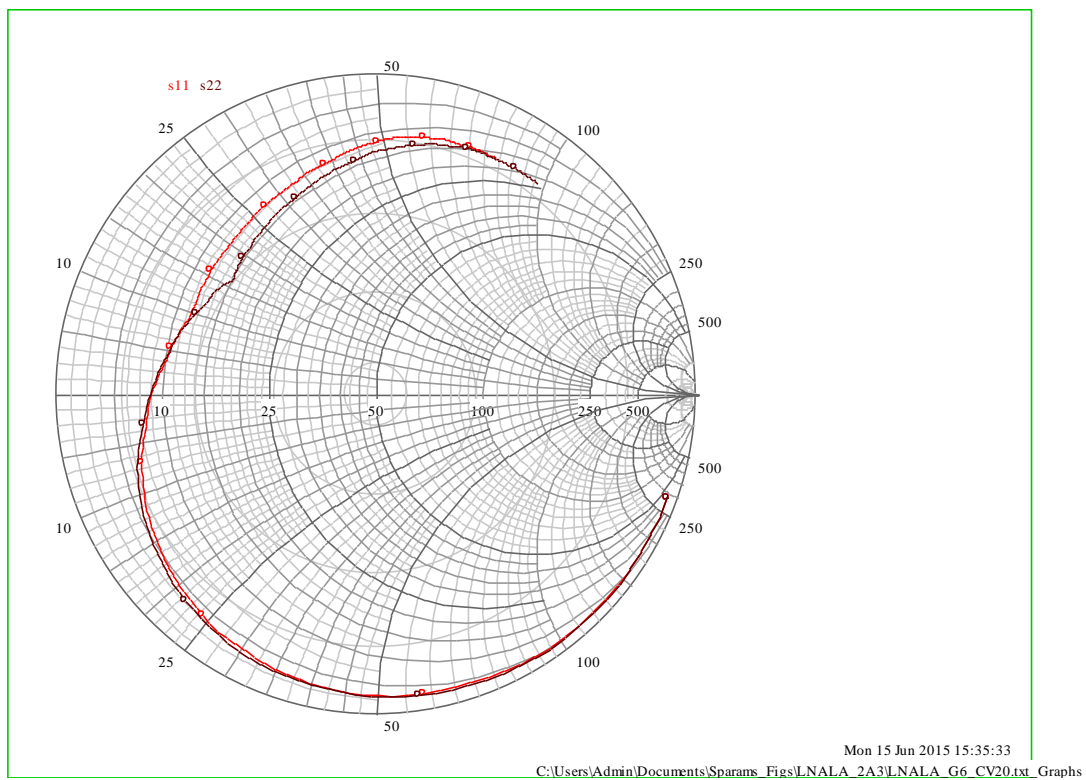


Figure 91 LNALA Sample=3 Gain=6, Cap_Var =20 Short=0

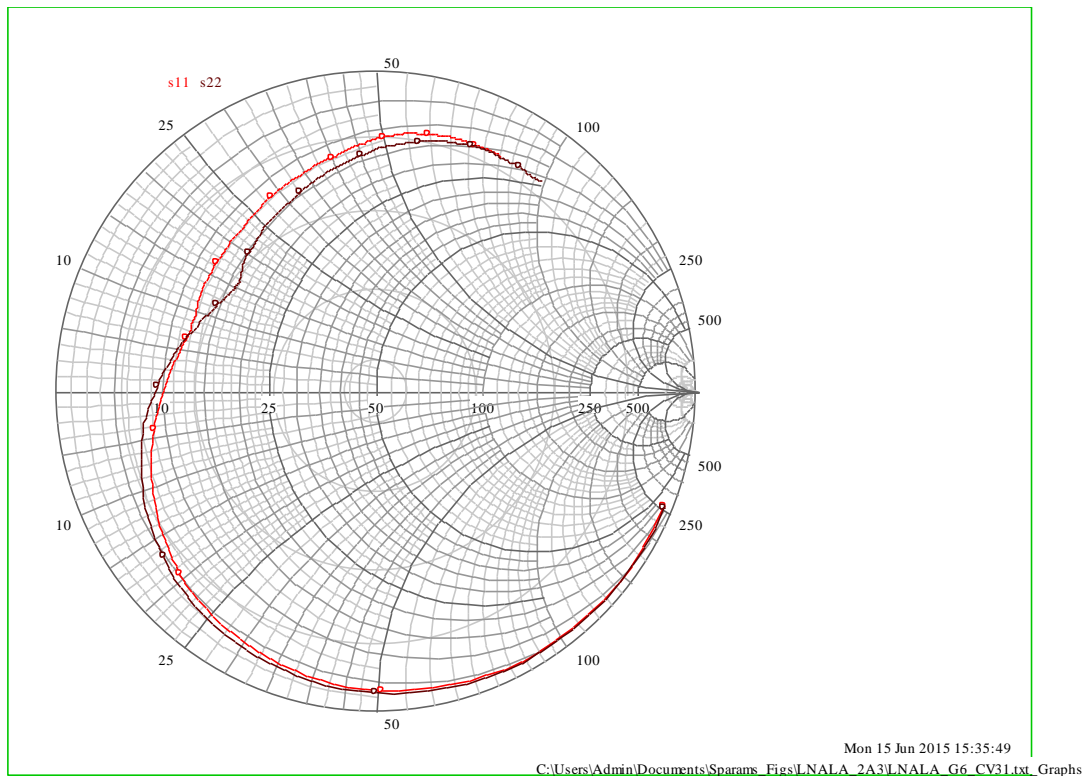


Figure 92 LNALA Sample=3 Gain=6, Cap_Var =31 Short=0

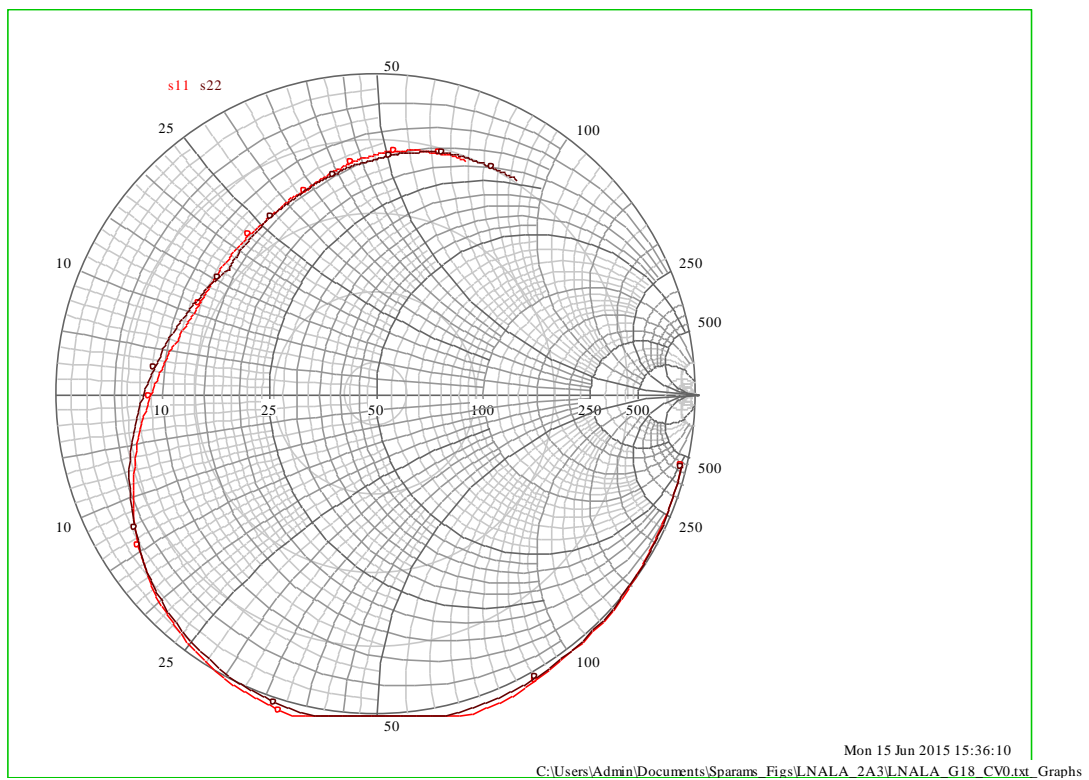


Figure 93 LNALA Sample=3 Gain=18, Cap_Var =0 Short=0

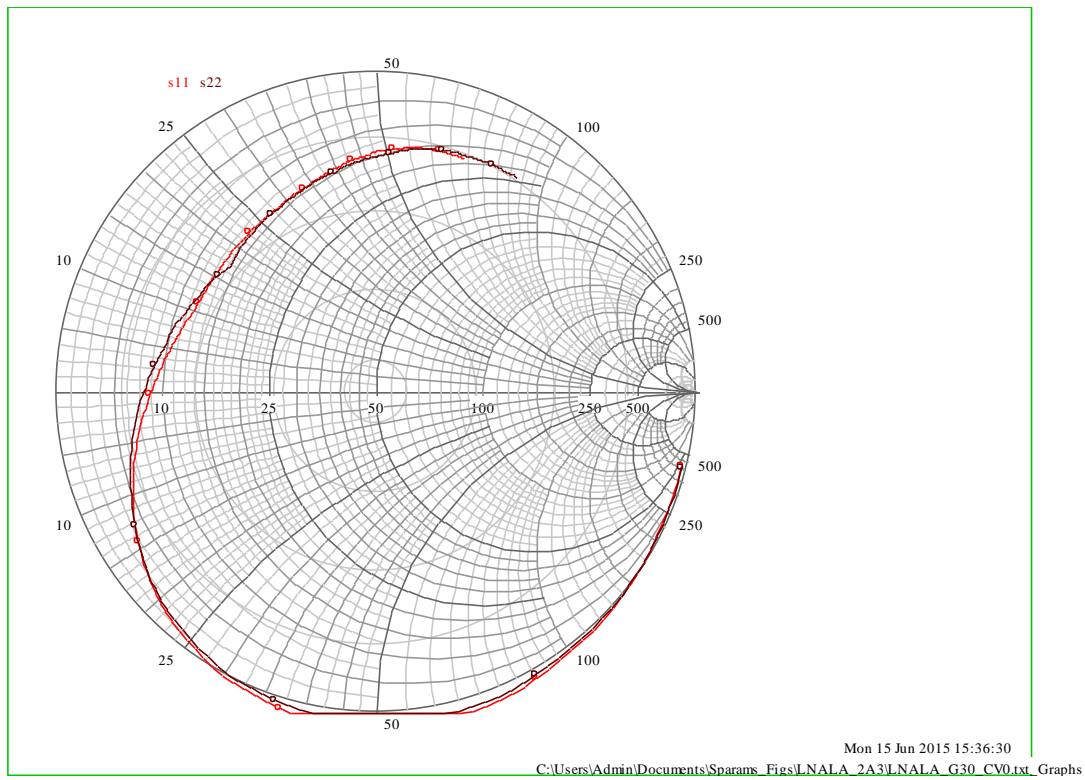


Figure 94 LNALA Sample=3 Gain=31, Cap_Var =0 Short=0

4.9 LNAL Channel B Sample 1

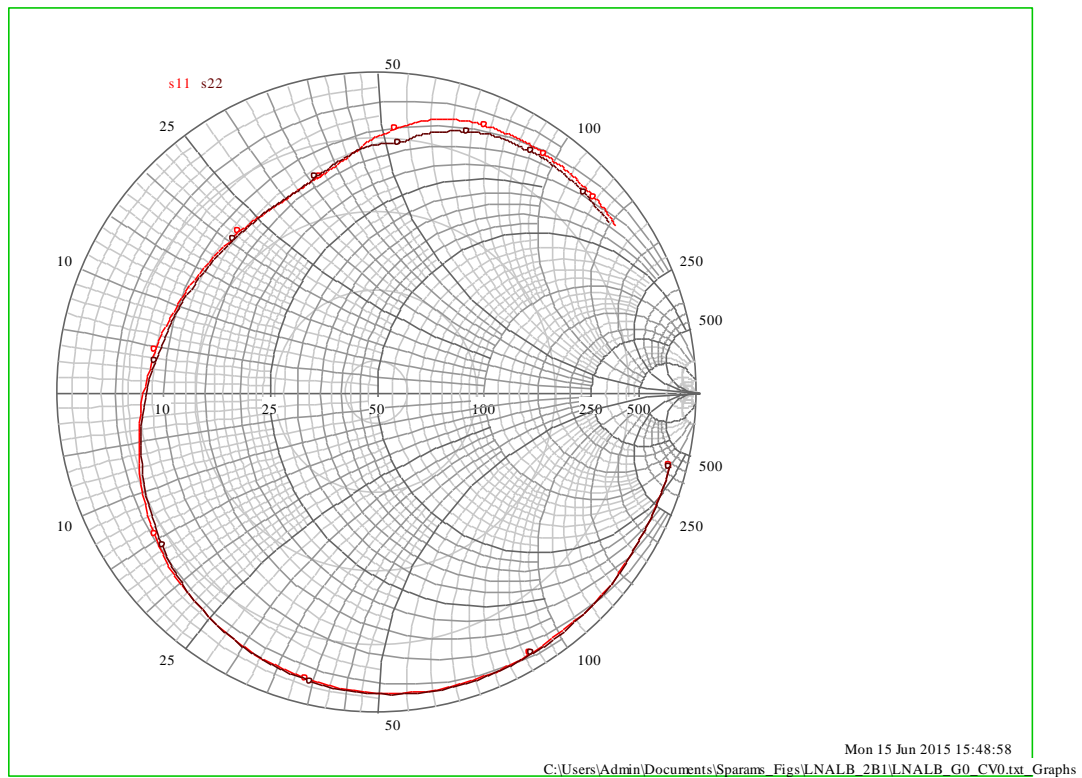


Figure 95 LNALB Sample=1 Gain=0, Cap_Var=0 Short=0

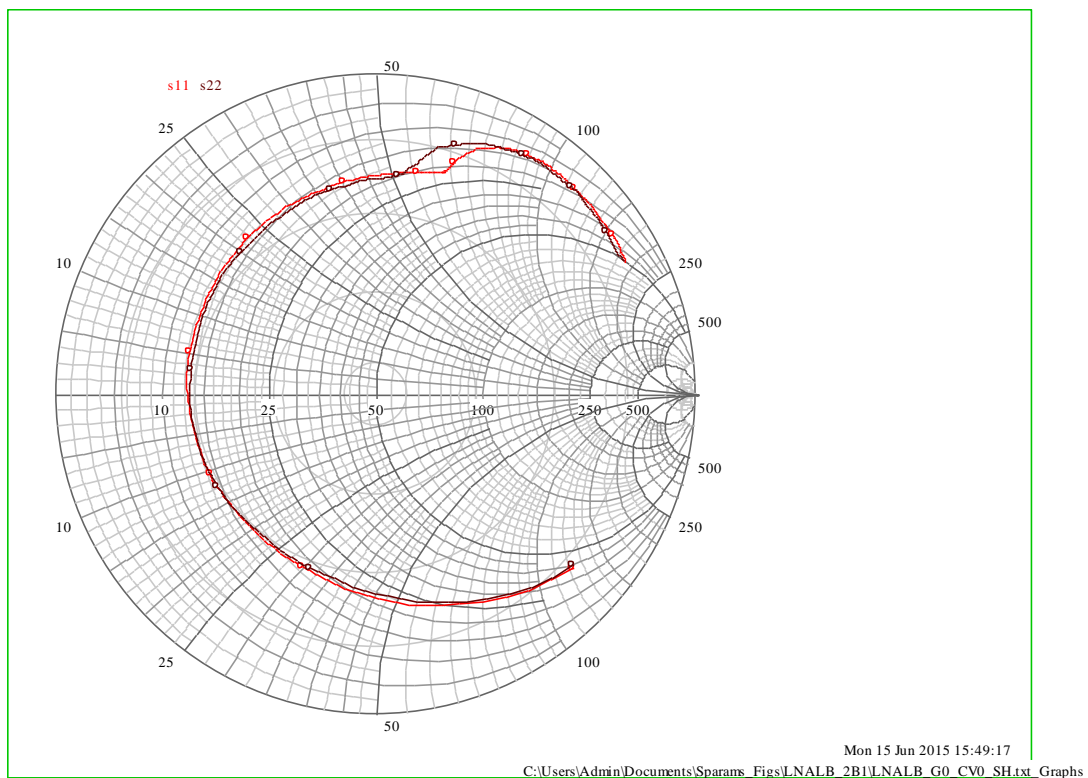


Figure 96 LNALB Sample=1 Gain=0, Cap_Var=0 Short=1

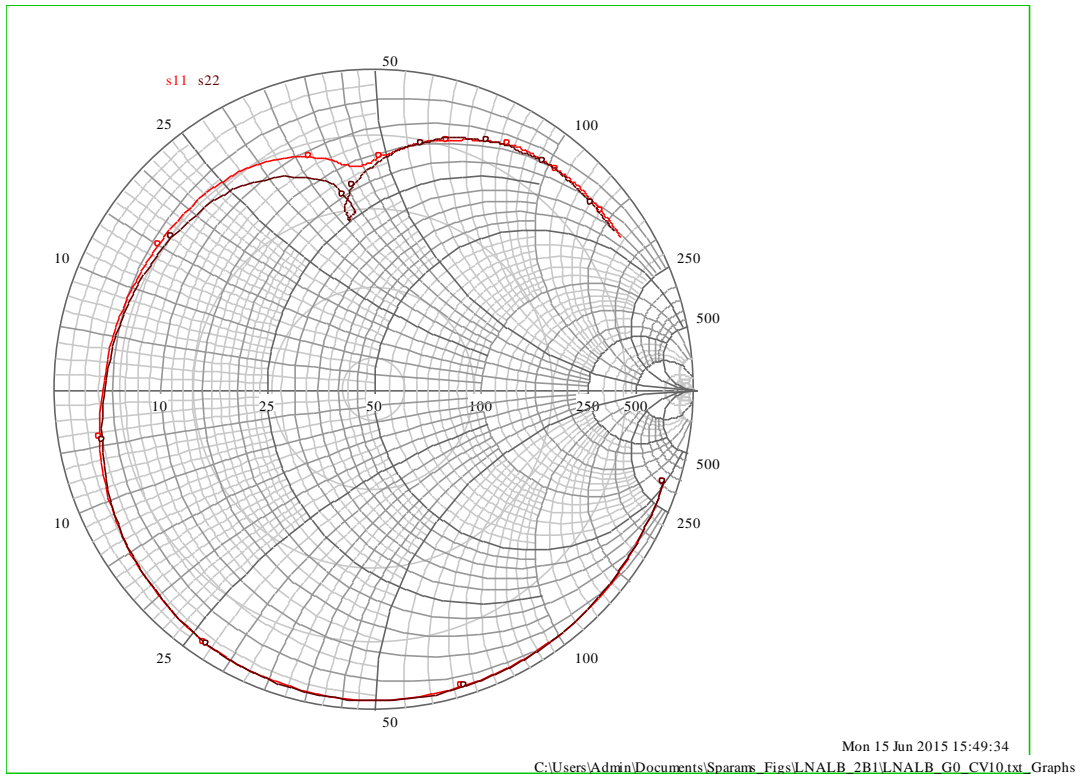


Figure 97 LNALB Sample=1 Gain=0, Cap_Var =10 Short=0

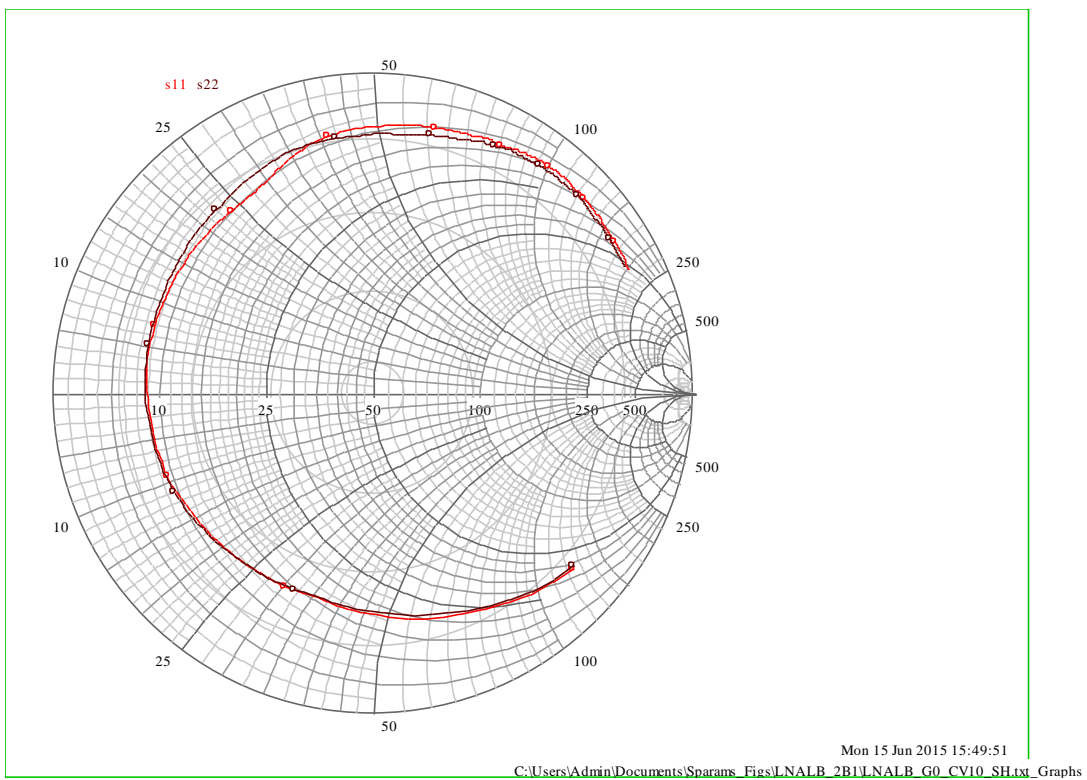


Figure 98 LNALB Sample=1 Gain=0, Cap_Var =10 Short=1

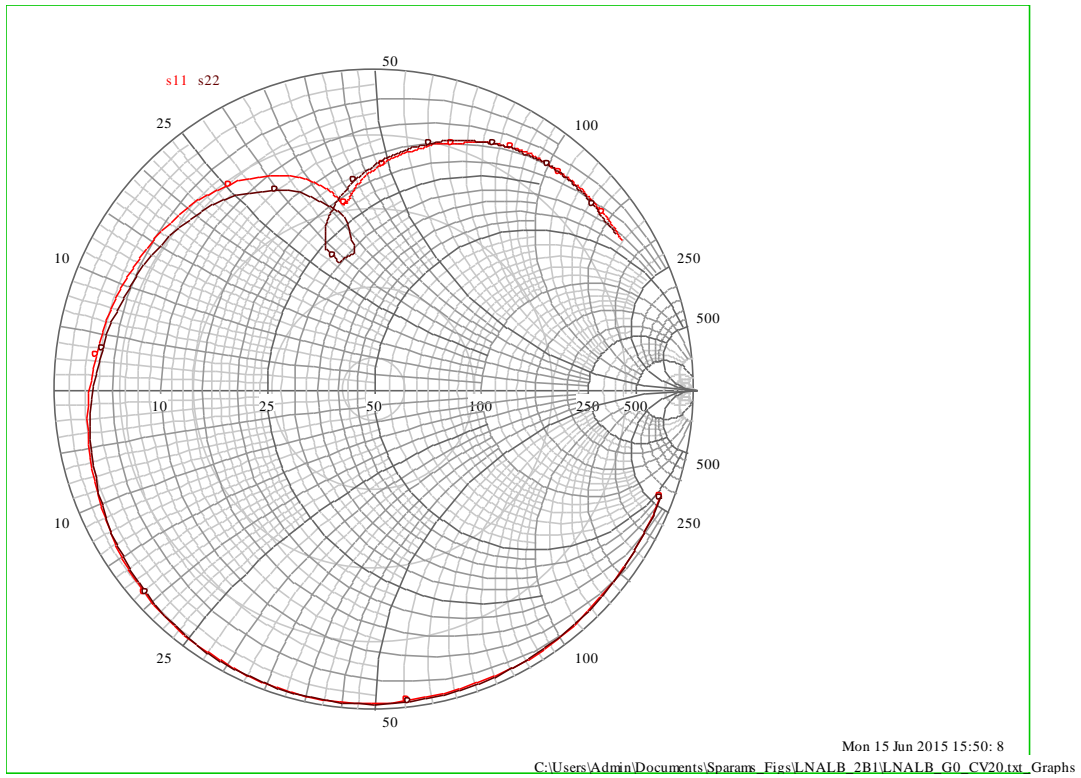


Figure 99 LNALB Sample=1 Gain=0, Cap_Var =20 Short=0

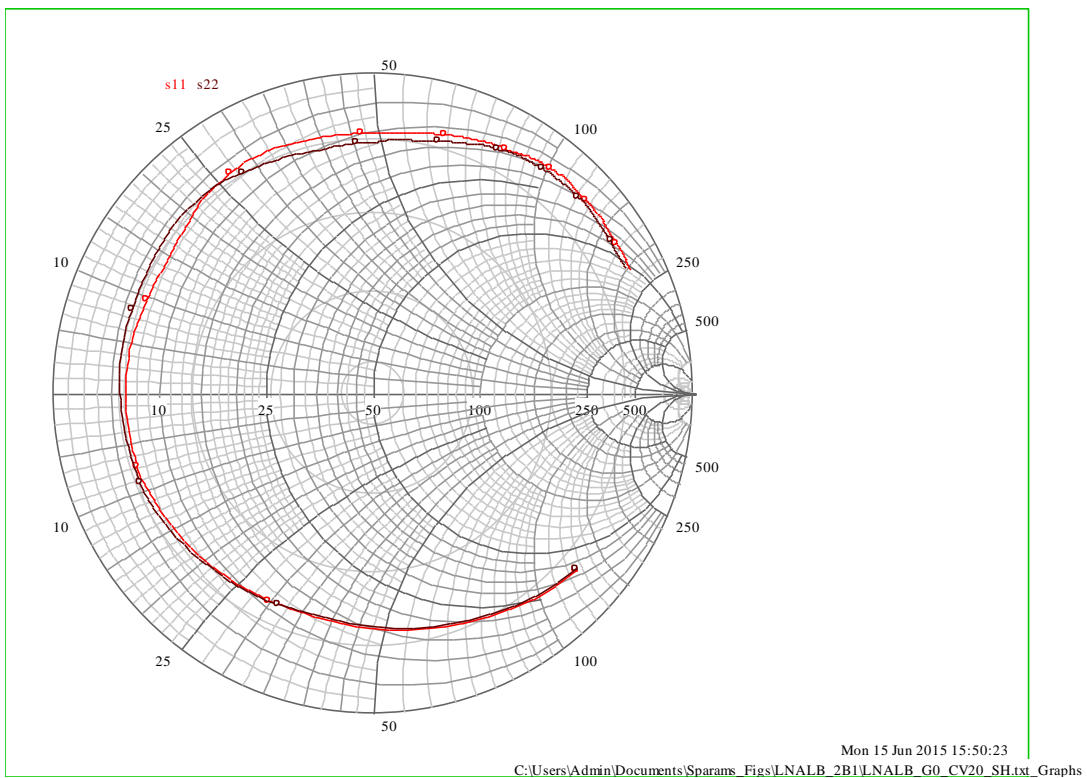


Figure 100 LNALB Sample=1 Gain=0, Cap_Var =20 Short=1

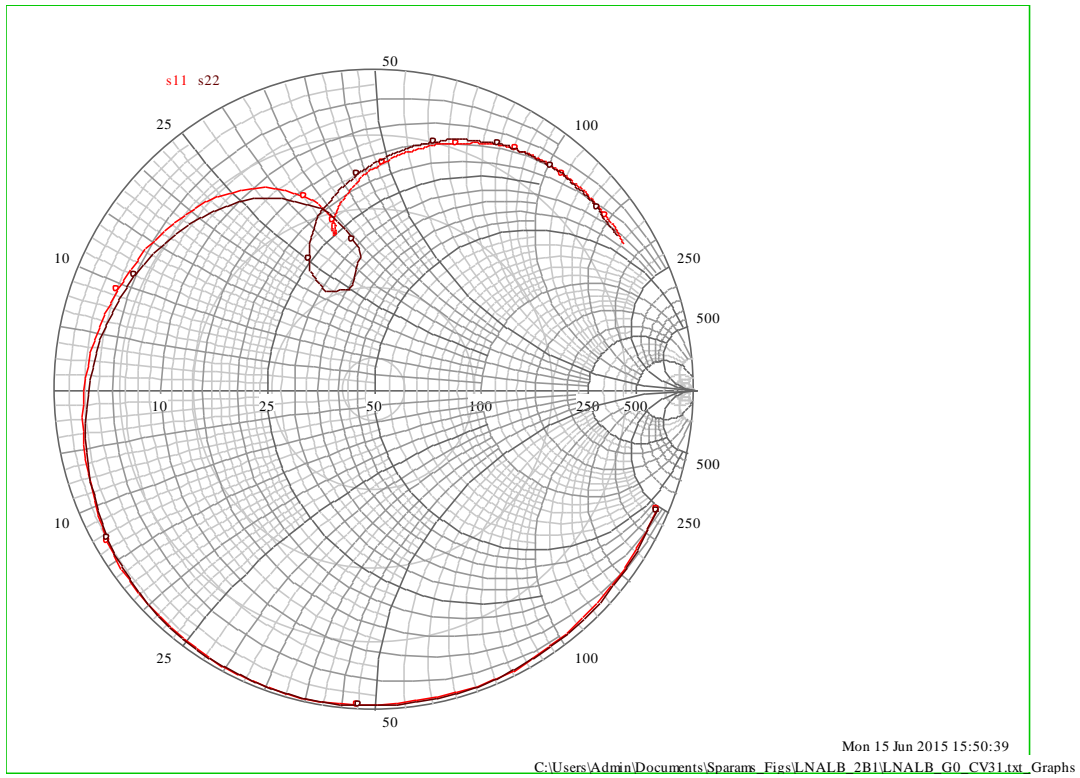


Figure 101 LNALB Sample=1 Gain=0, Cap_Var =31 Short=0

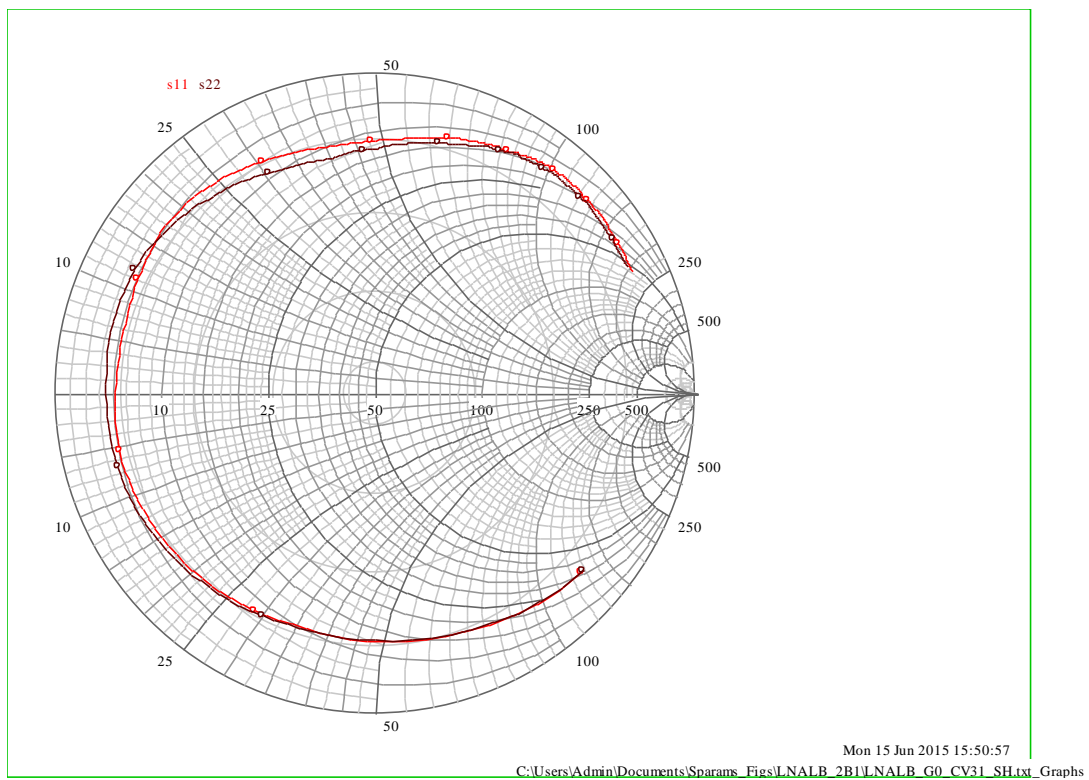


Figure 102 LNALB Sample=1 Gain=0, Cap_Var =31 Short=1

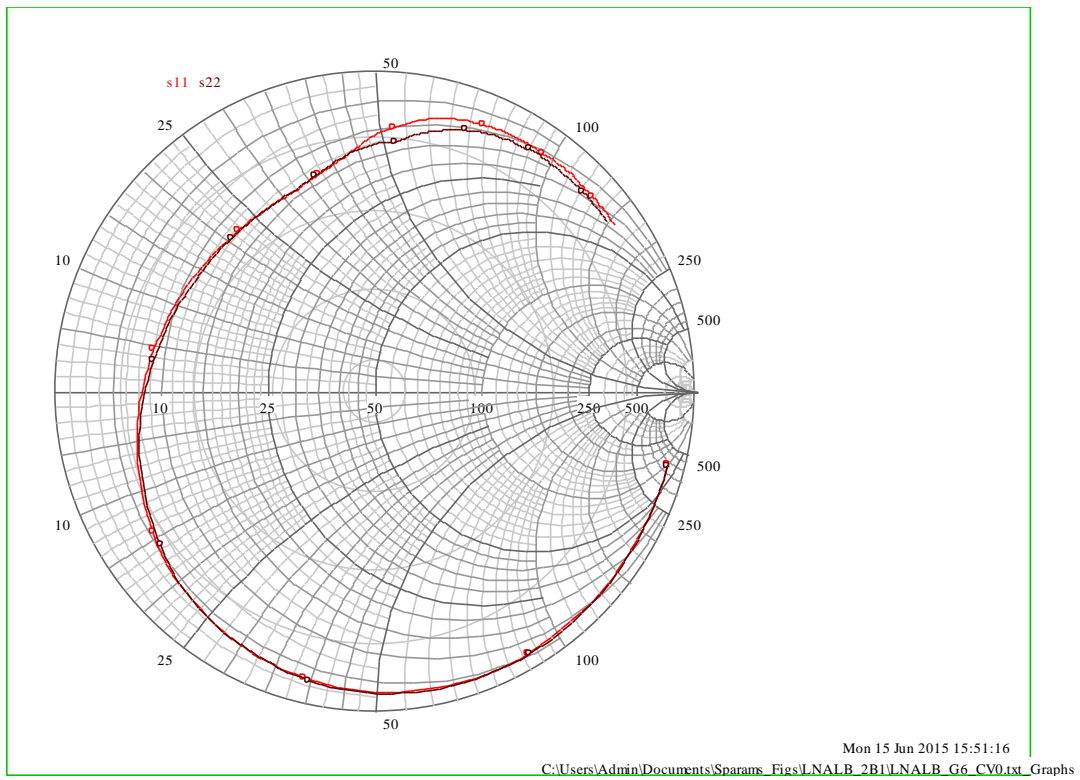


Figure 103 LNALB Sample=1 Gain=6, Cap_Var =0 Short=0

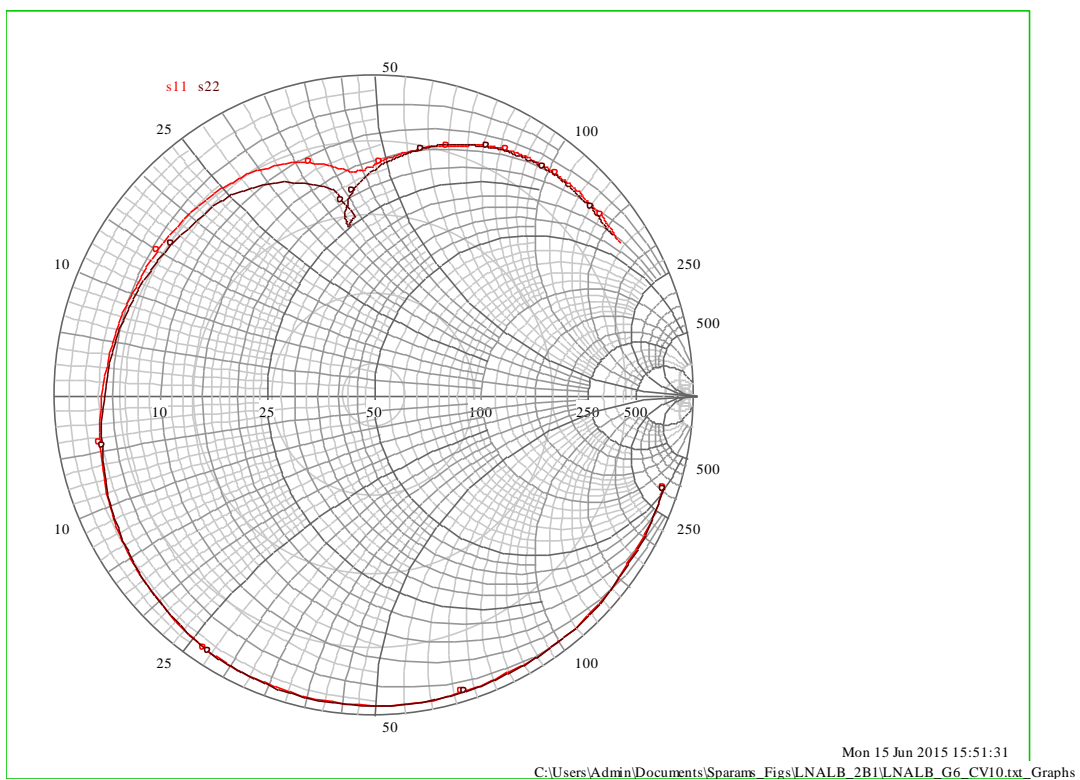


Figure 104 LNALB Sample=1 Gain=6, Cap_Var =10 Short=0

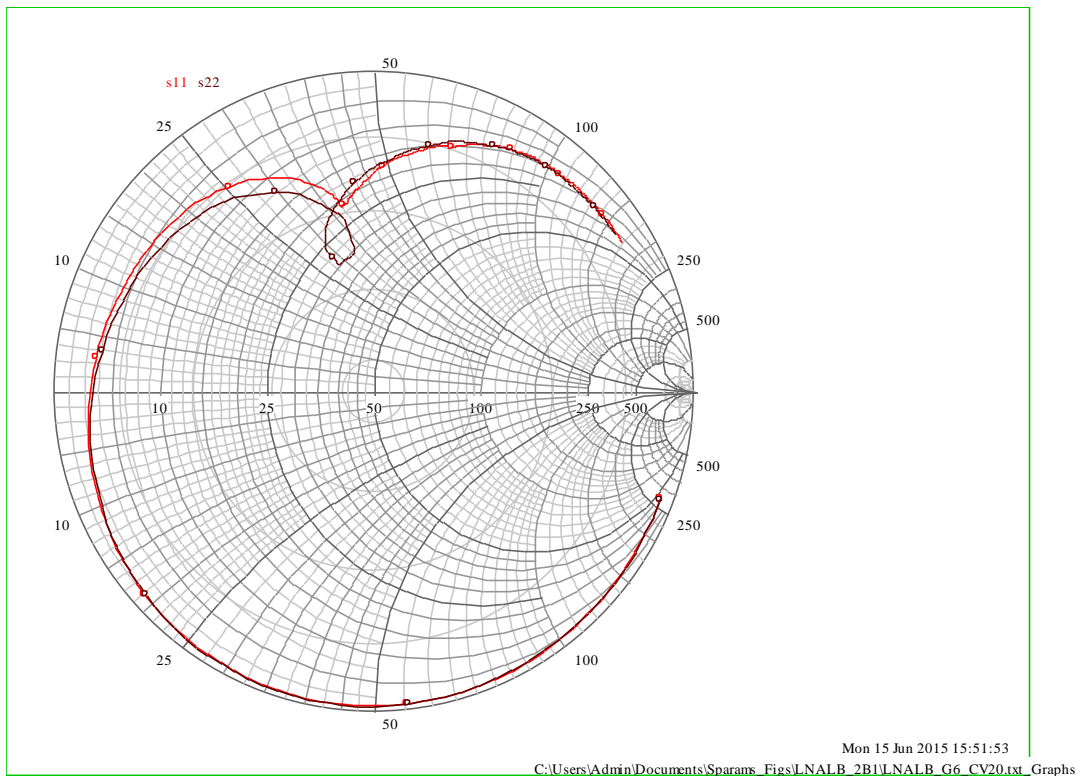


Figure 105 LNALB Sample=1 Gain=6, Cap_Var =20 Short=0

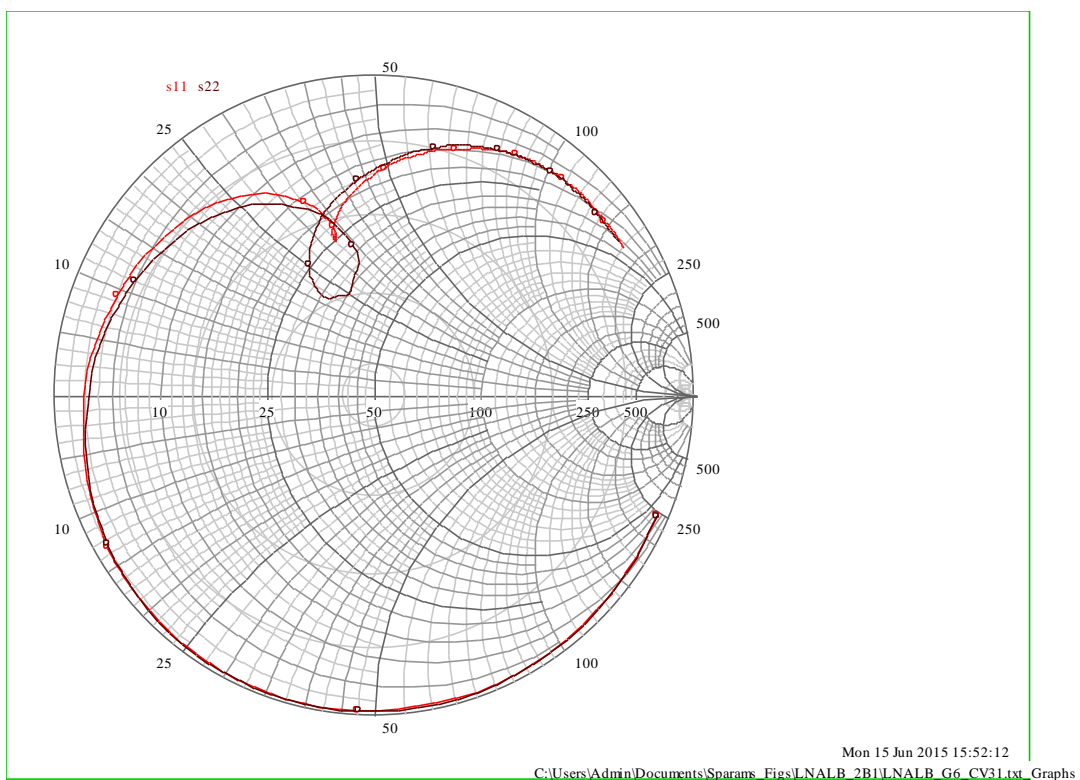


Figure 106 LNALB Sample=1 Gain=6, Cap_Var =31 Short=0

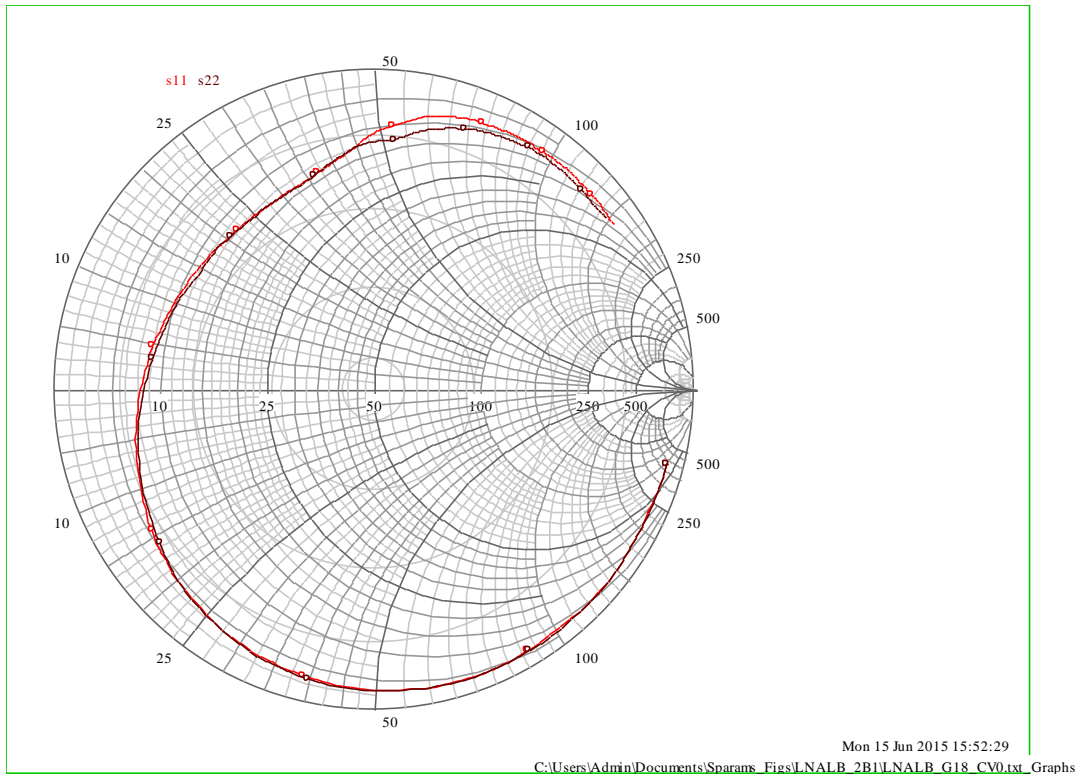


Figure 107 LNALB Sample=1 Gain=18, Cap_Var =0 Short=0

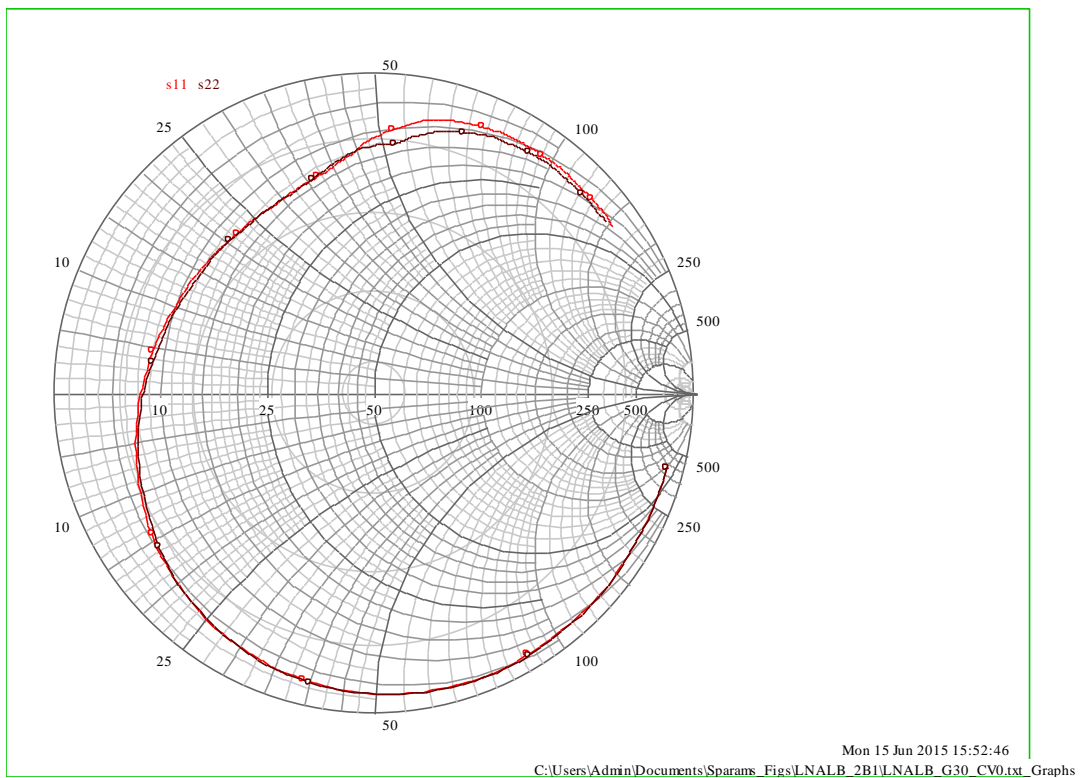


Figure 108 LNALB Sample=1 Gain=31, Cap_Var =0 Short=0

4.10 LNAL Channel B Sample 2

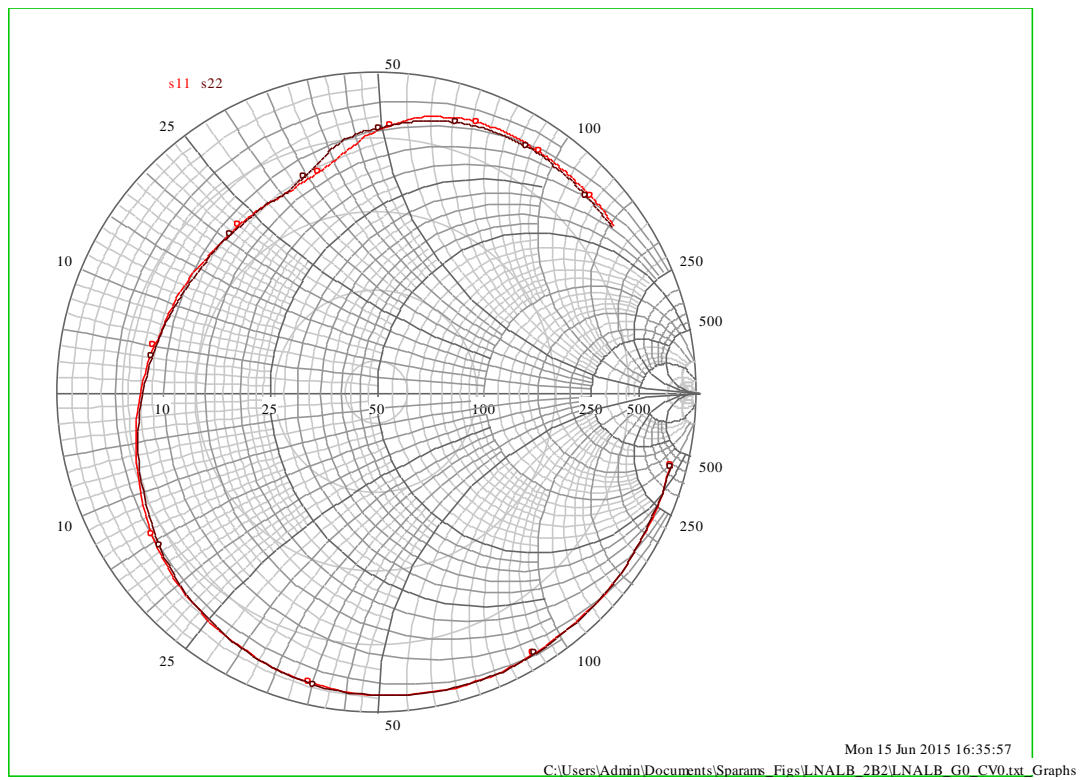


Figure 109 LNALB Sample=2 Gain=0, Cap_Var=0 Short=0

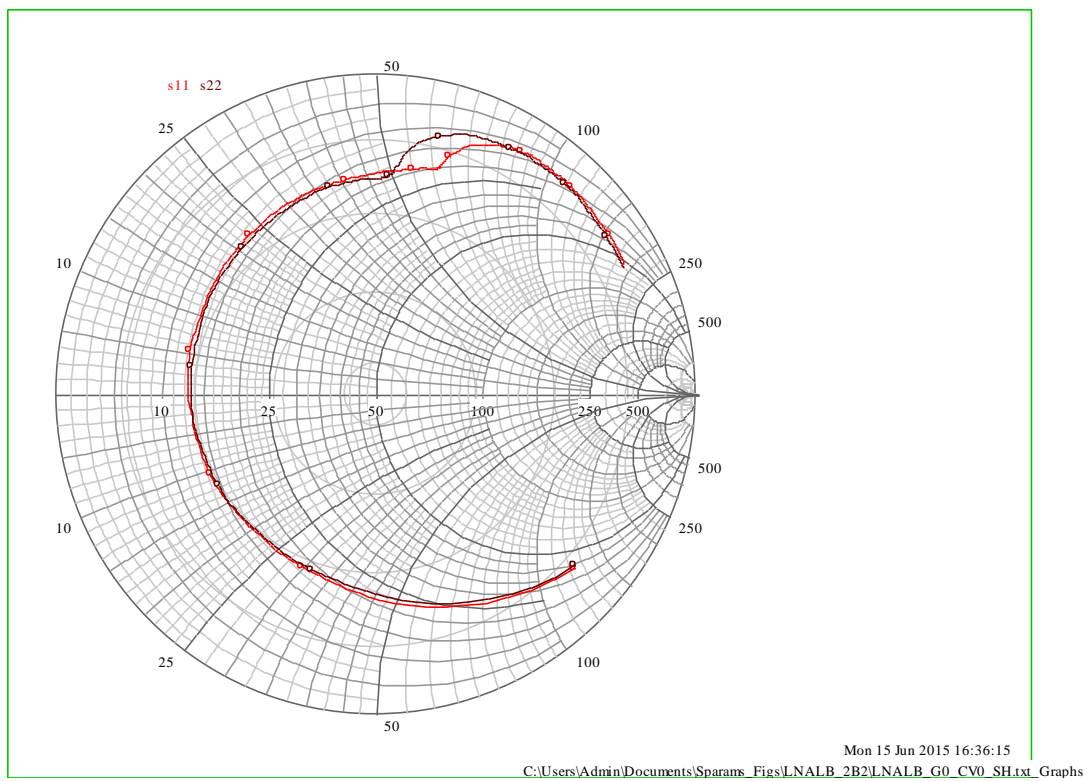


Figure 110 LNALB Sample=2 Gain=0, Cap_Var=0 Short=1

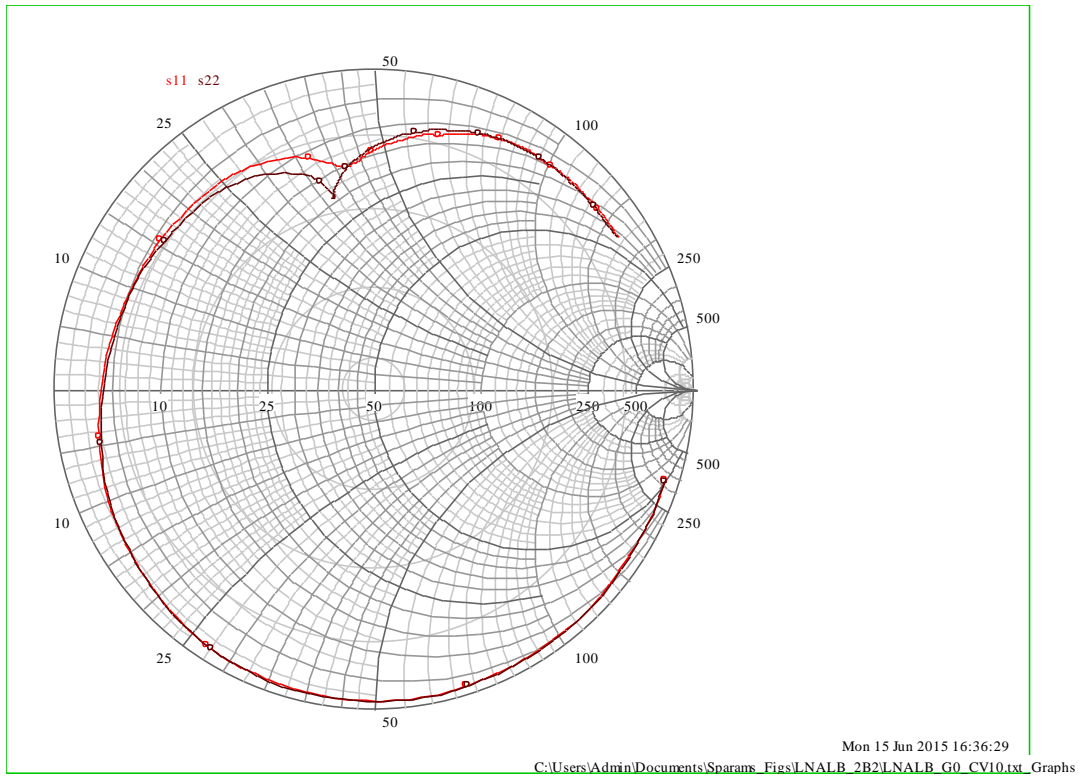


Figure 111 LNALB Sample=2 Gain=0, Cap_Var =10 Short=0

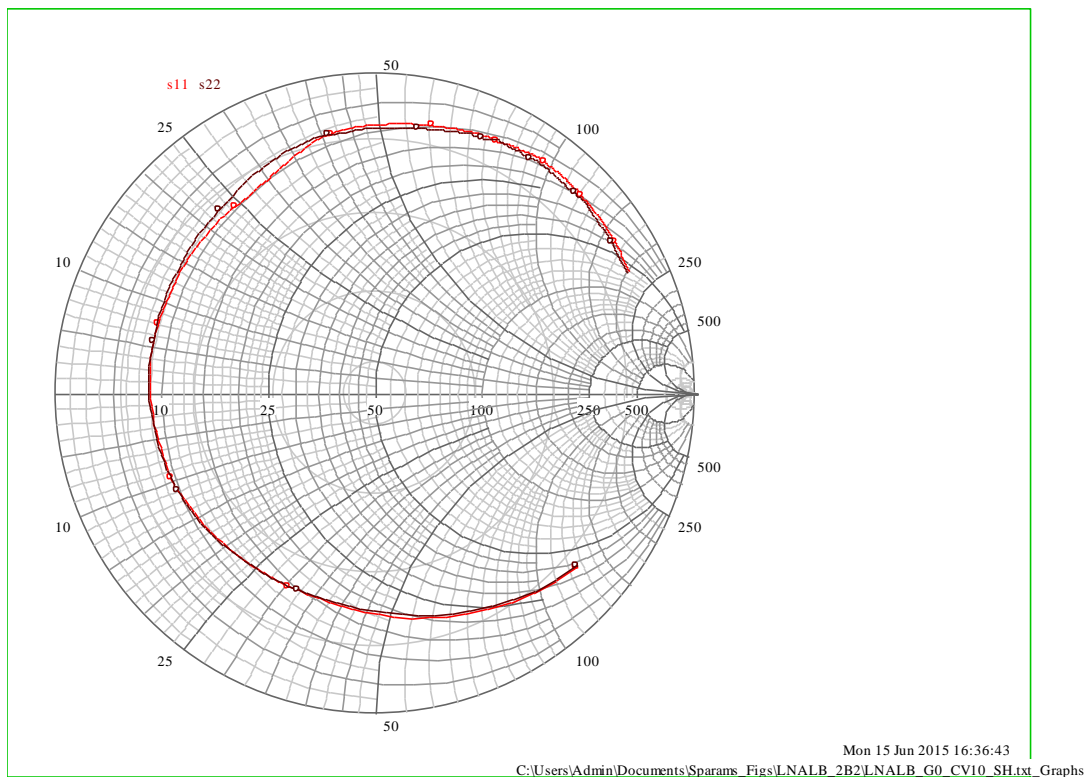


Figure 112 LNALB Sample=2 Gain=0, Cap_Var =10 Short=1

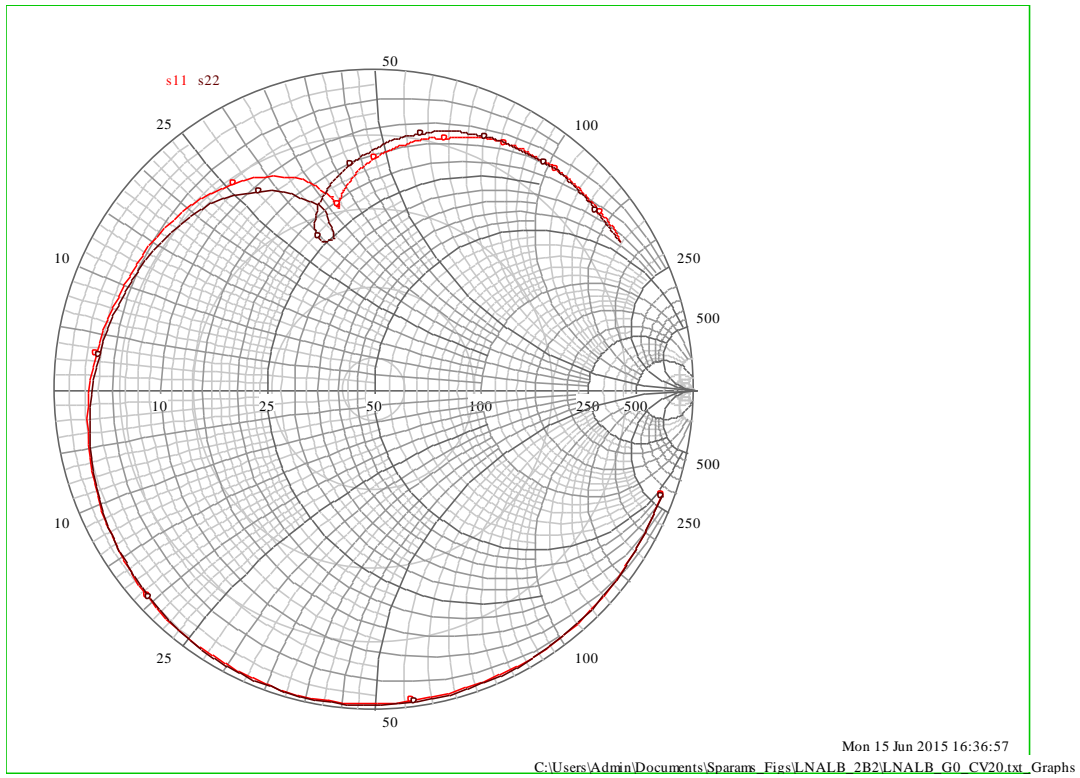


Figure 113 LNALB Sample=2 Gain=0, Cap_Var =20 Short=0

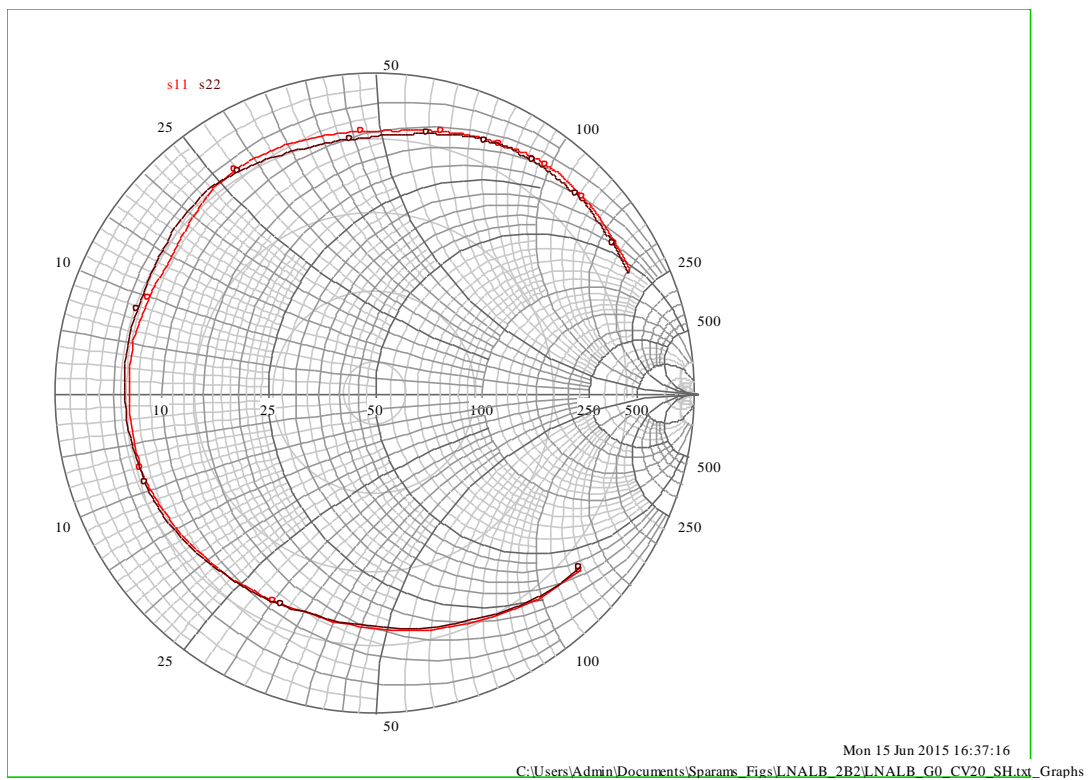


Figure 114 LNALB Sample=2 Gain=0, Cap_Var =20 Short=1

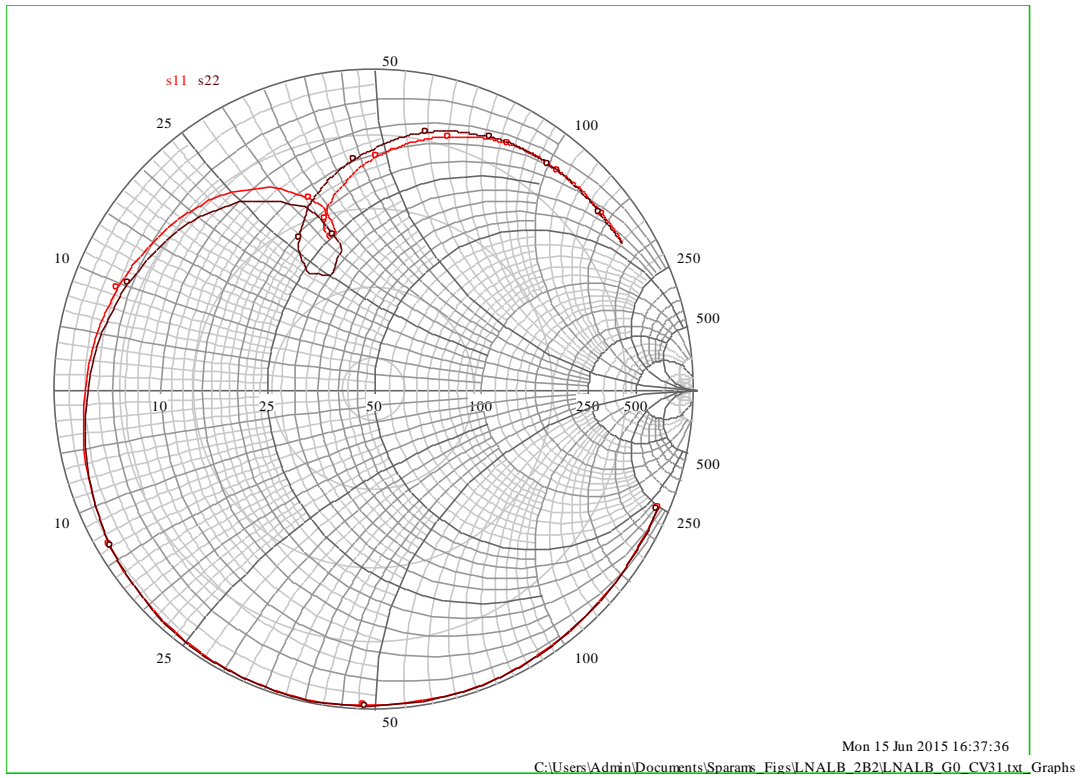


Figure 115 LNALB Sample=2 Gain=0, Cap_Var =31 Short=0

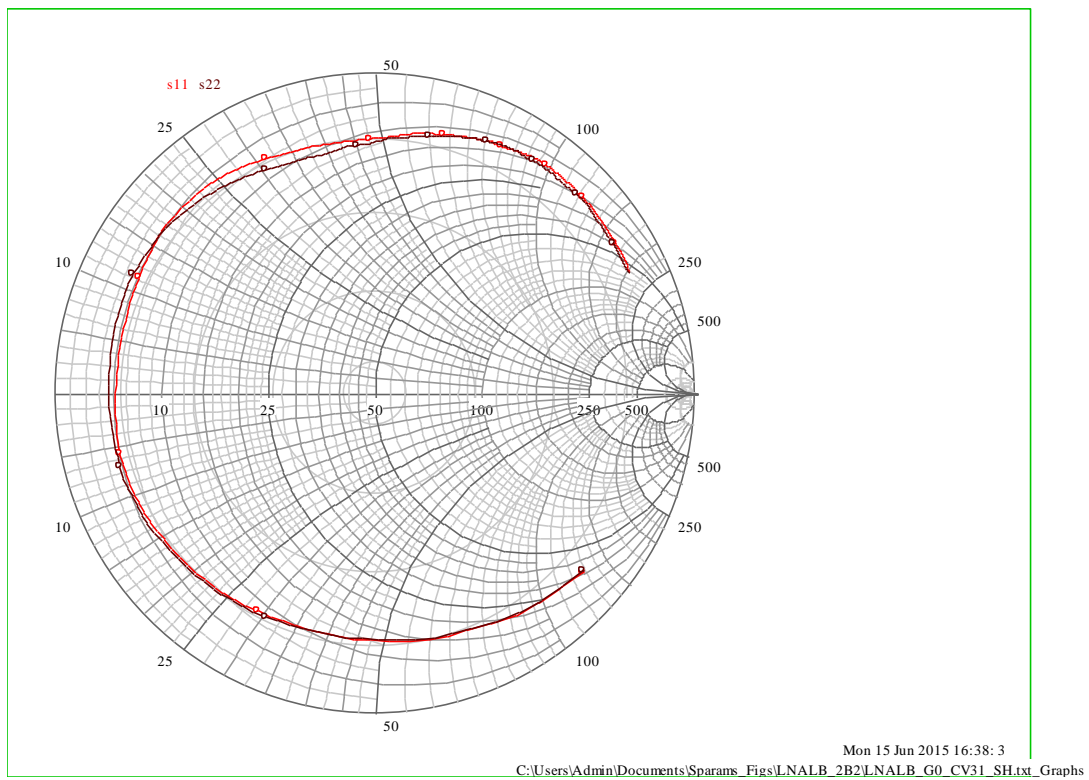


Figure 116 LNALB Sample=2 Gain=0, Cap_Var =31 Short=1

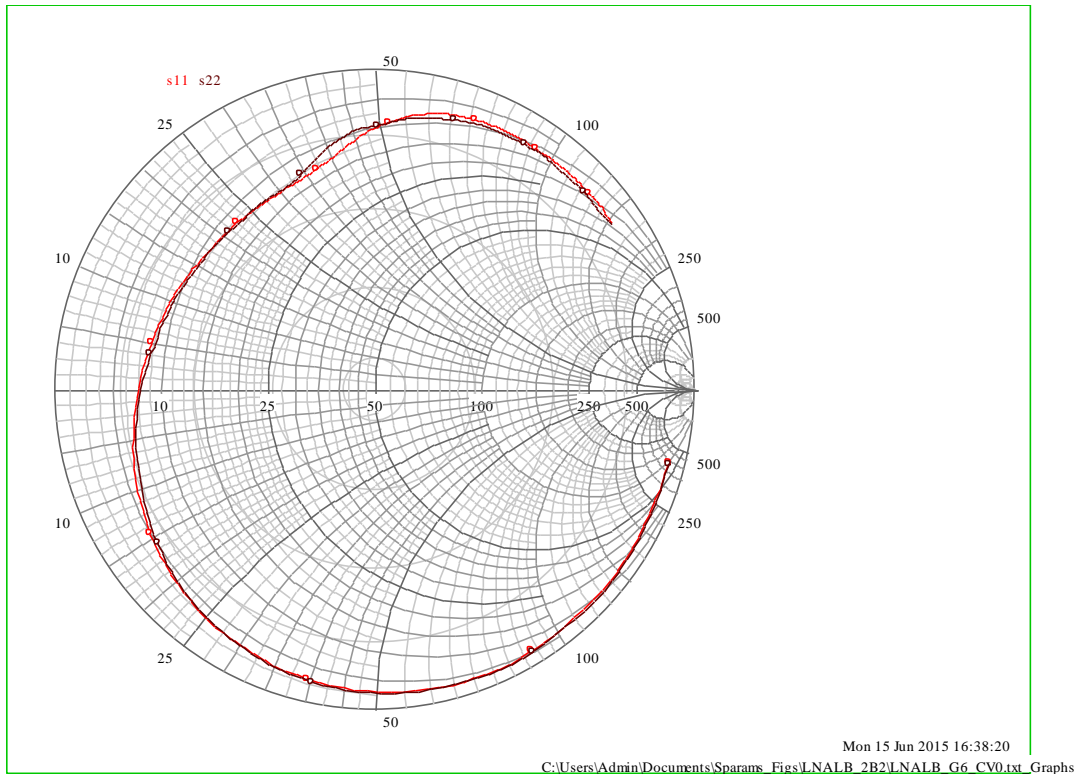


Figure 117 LNALB Sample=2 Gain=6, Cap_Var =0 Short=0

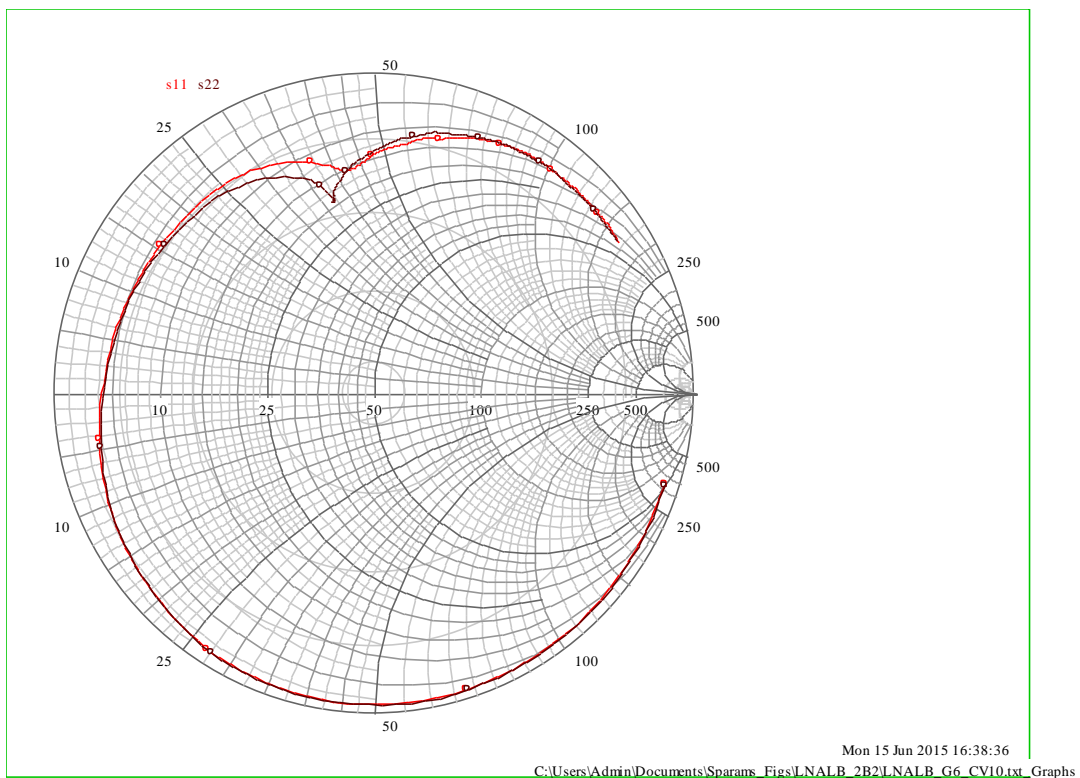


Figure 118 LNALB Sample=2 Gain=6, Cap_Var =10 Short=0

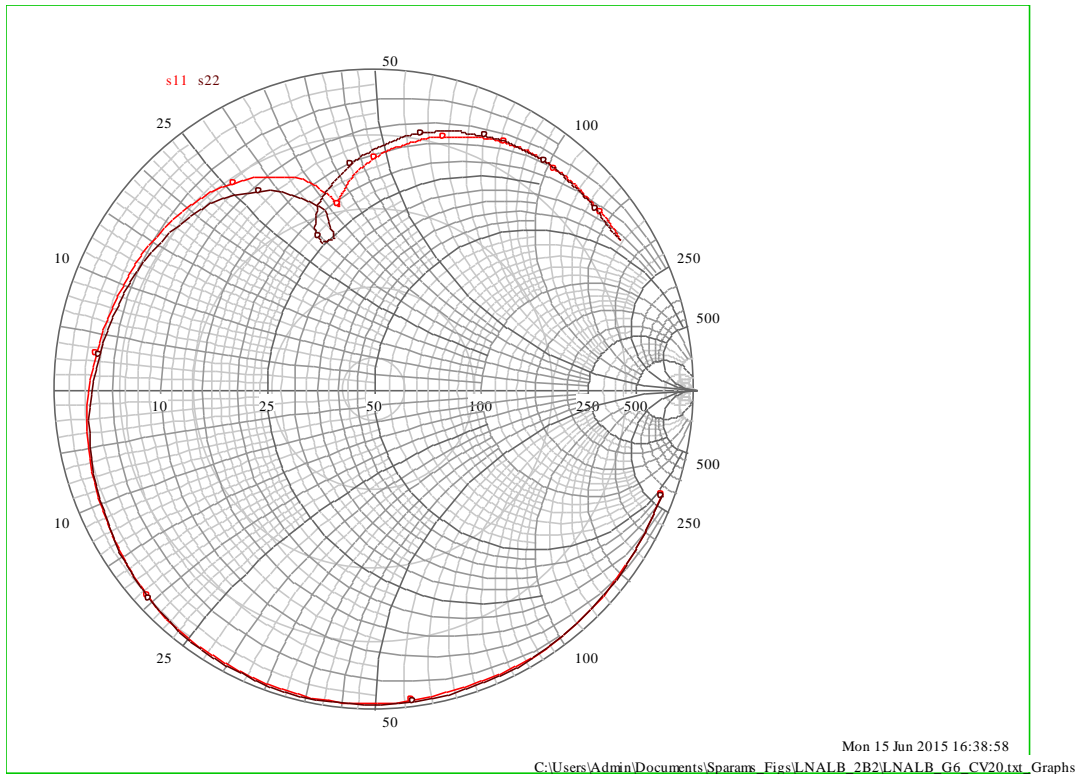


Figure 119 LNALB Sample=2 Gain=6, Cap_Var =20 Short=0

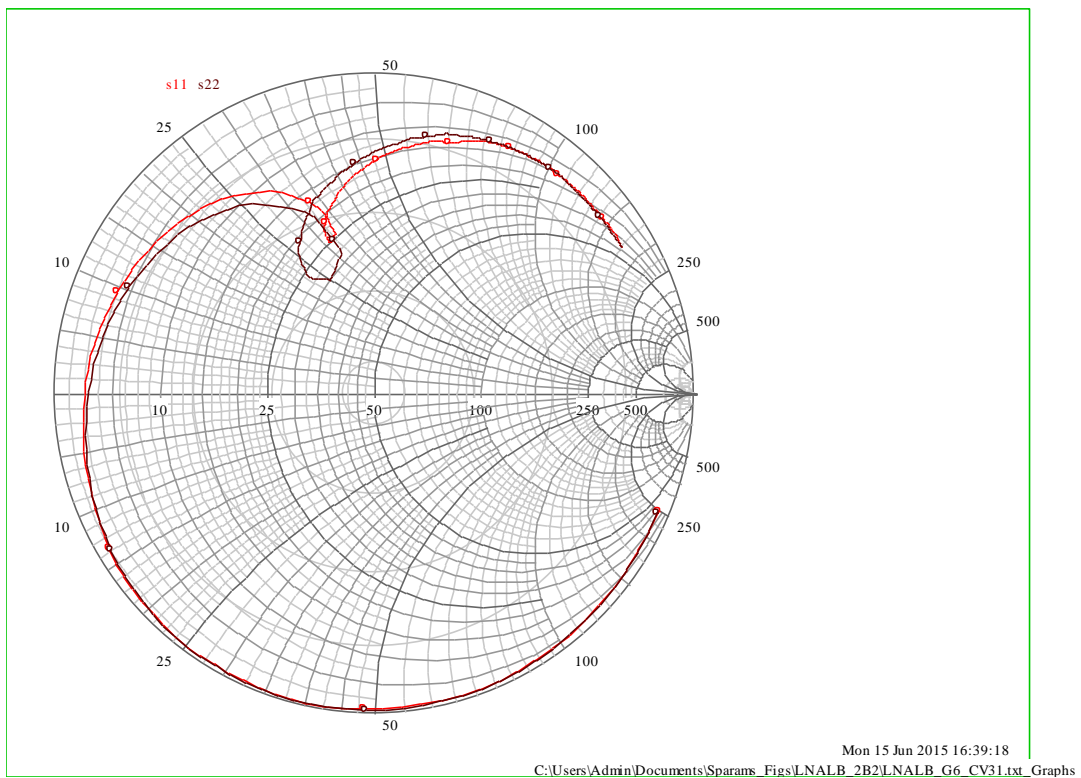


Figure 120 LNALB Sample=2 Gain=6, Cap_Var =31 Short=0

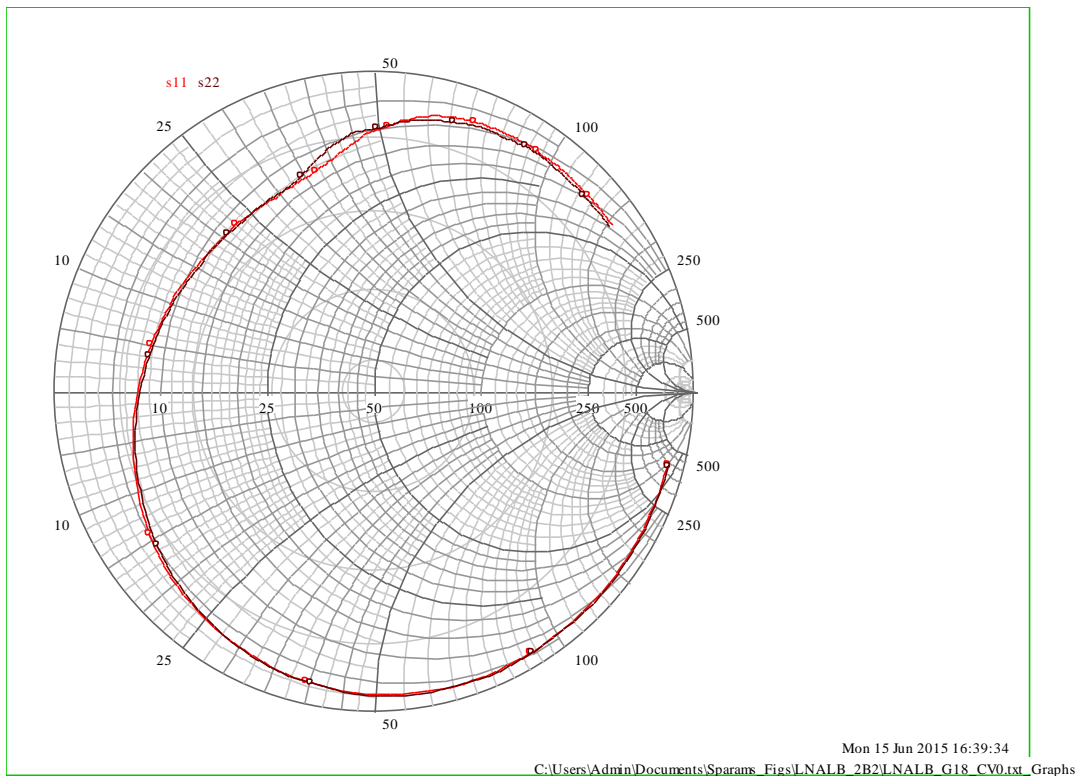


Figure 121 LNALB Sample=2 Gain=18, Cap_Var =0 Short=0

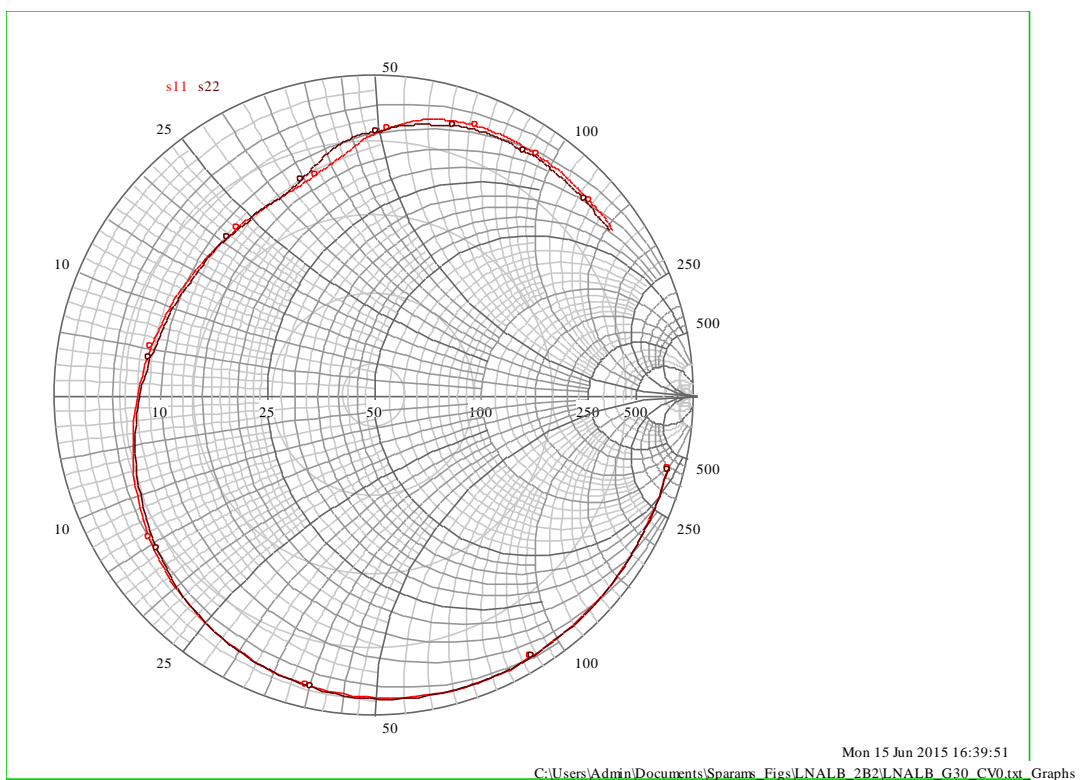


Figure 122 LNALB Sample=2 Gain=31, Cap_Var =0 Short=0

4.11 LNAL Channel B Sample 3

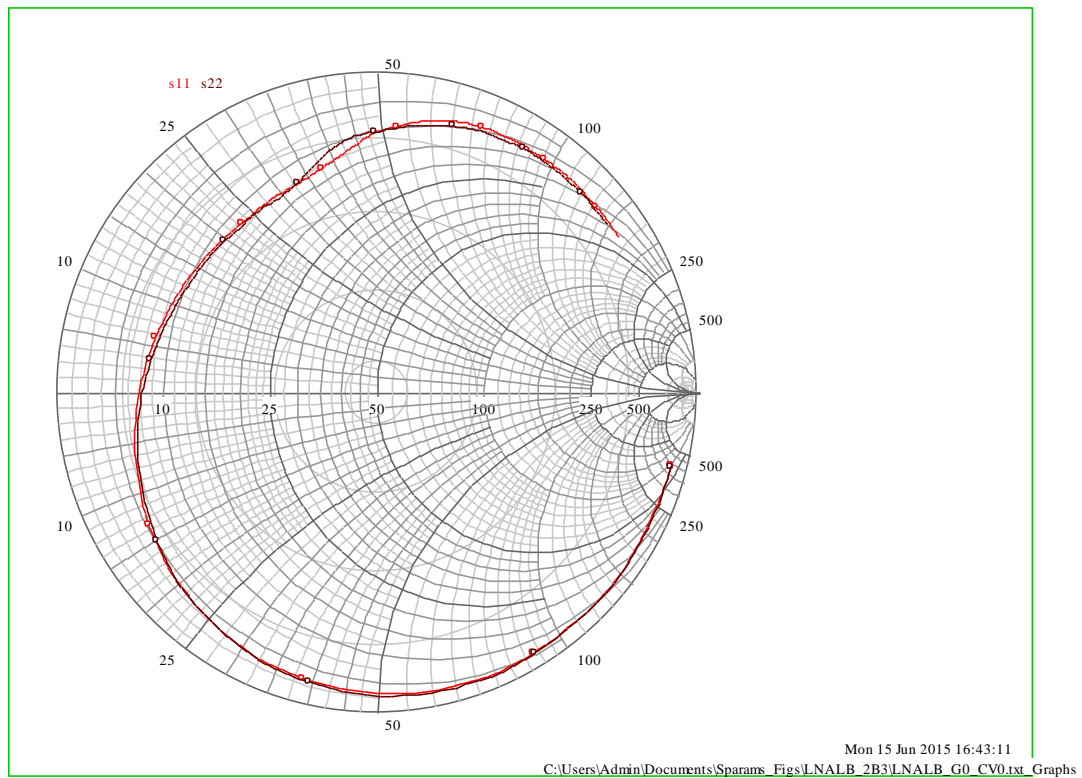


Figure 123 LNALB Sample=3 Gain=0, Cap_Var=0 Short=0

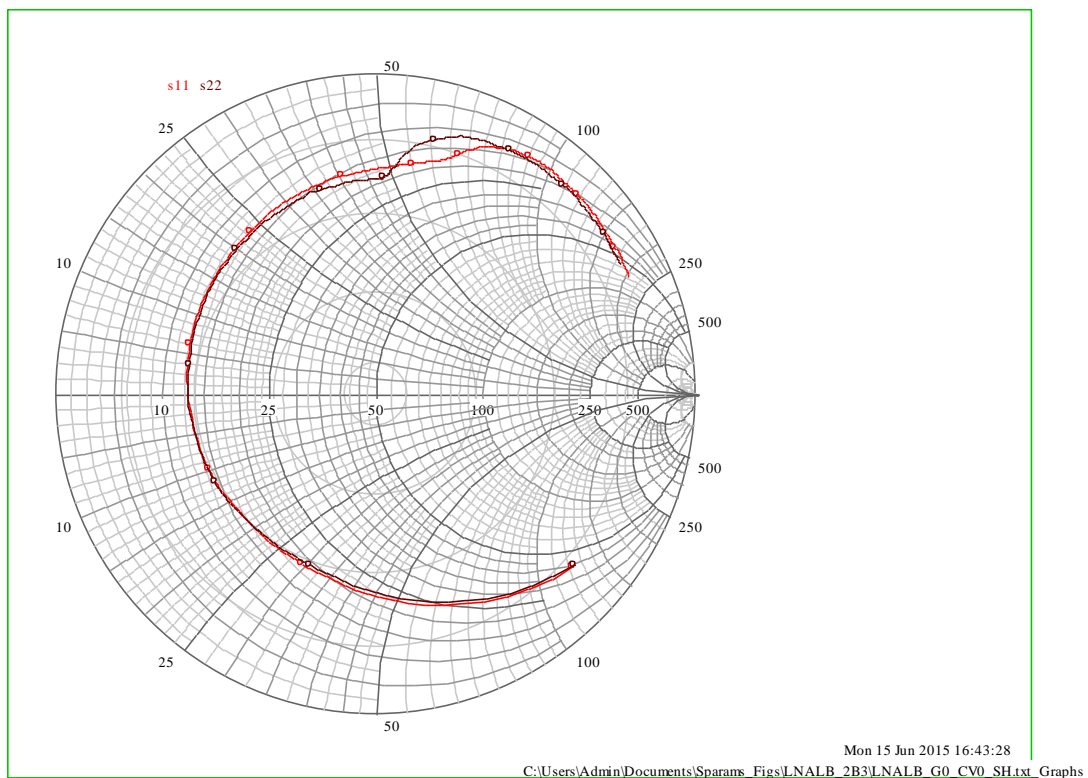


Figure 124 LNALB Sample=3 Gain=0, Cap_Var=0 Short=1

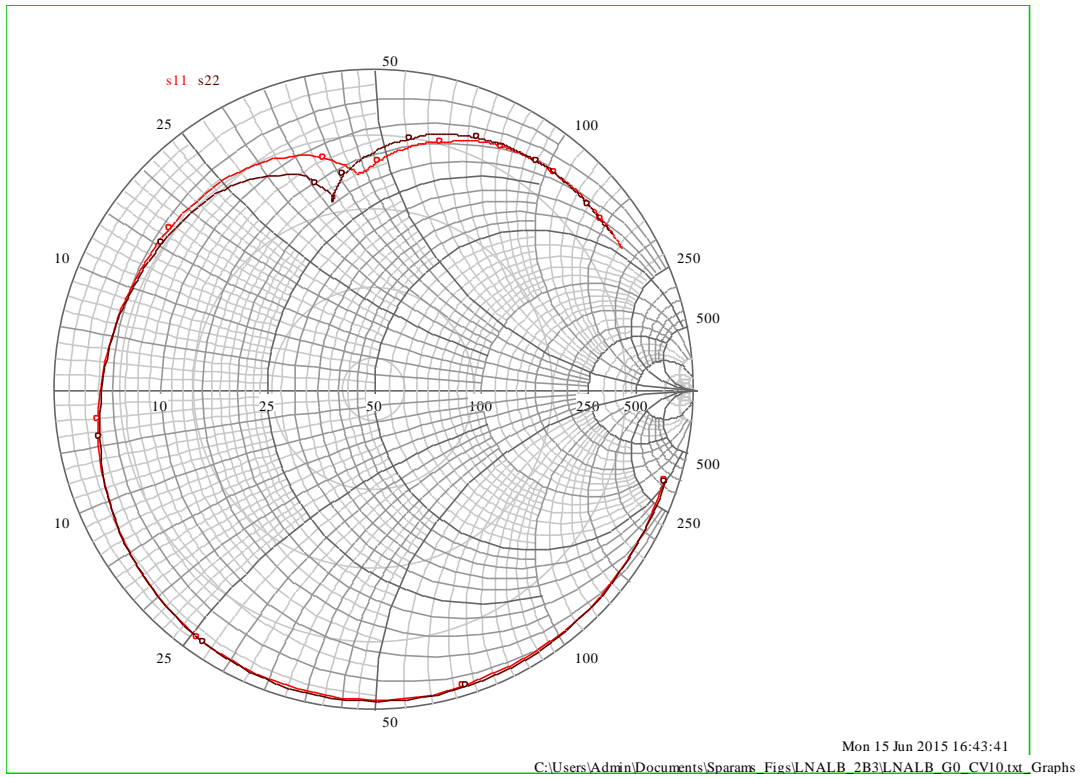


Figure 125 LNALB Sample=3 Gain=0, Cap_Var =10 Short=0

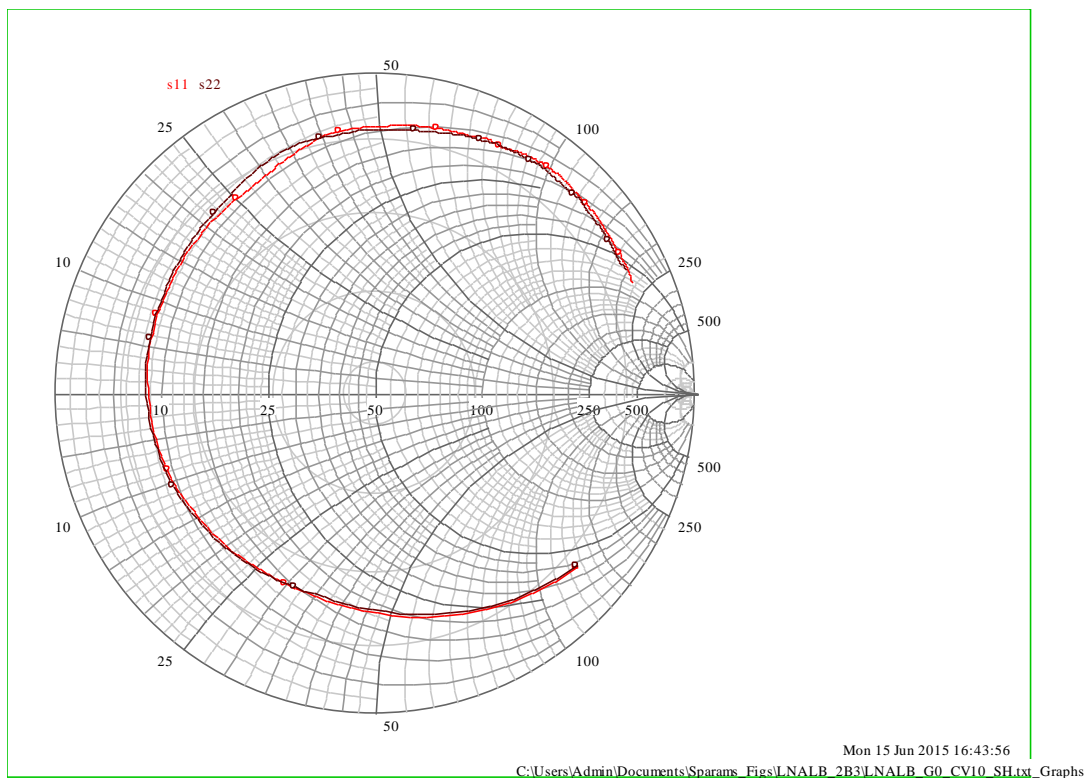


Figure 126 LNALB Sample=3 Gain=0, Cap_Var =10 Short=1

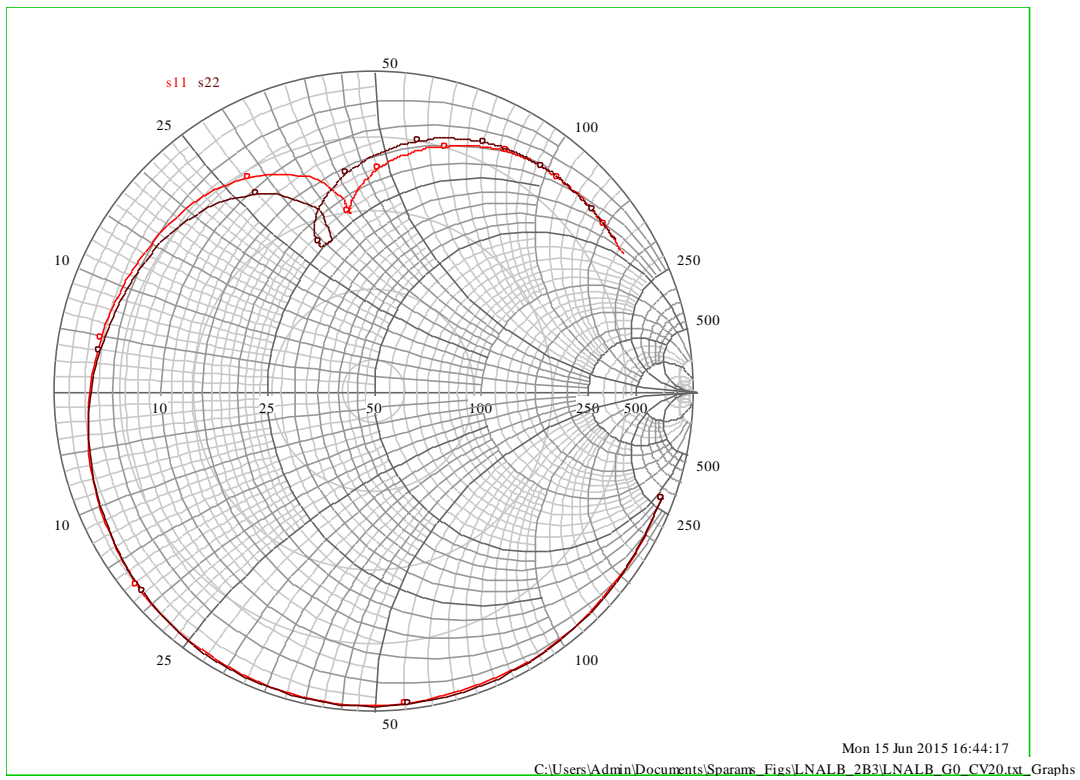


Figure 127 LNALB Sample=3 Gain=0, Cap_Var =20 Short=0

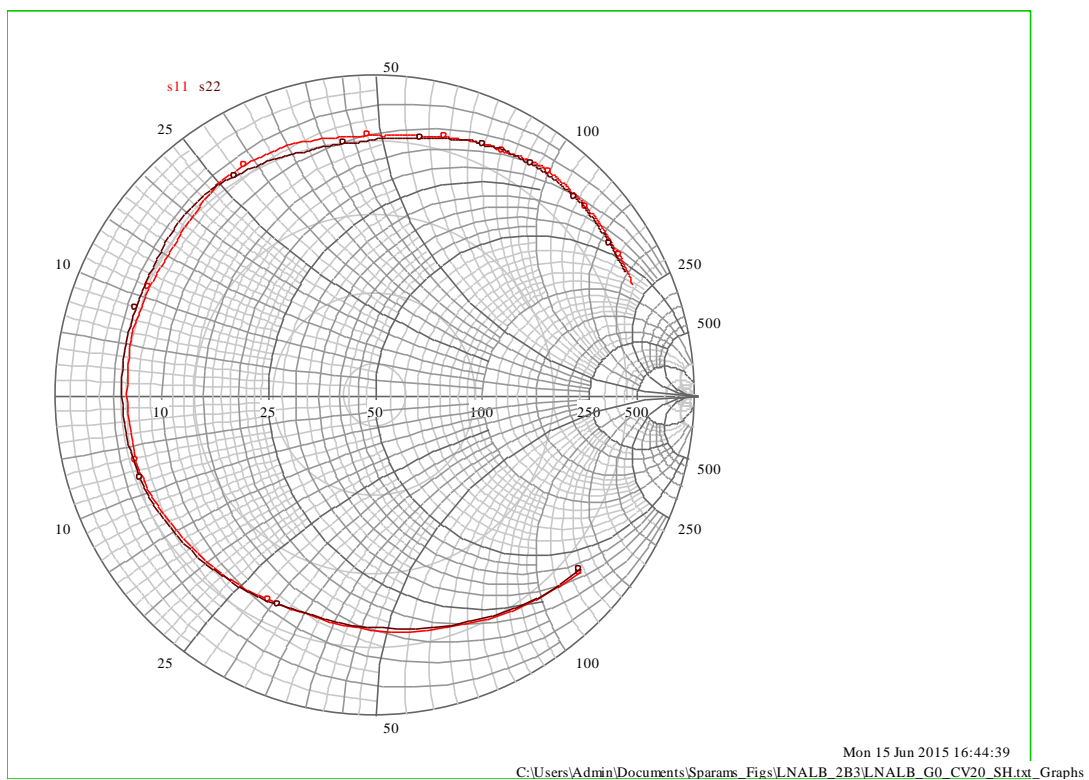


Figure 128 LNALB Sample=3 Gain=0, Cap_Var =20 Short=1

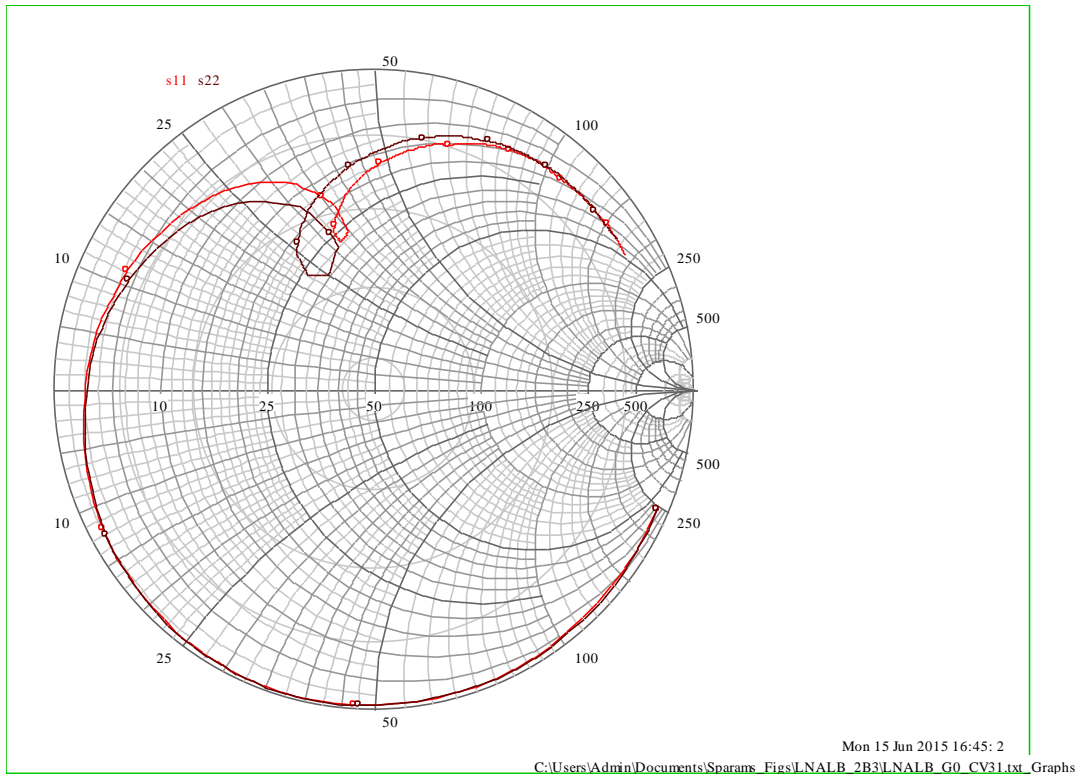


Figure 129 LNALB Sample=3 Gain=0, Cap_Var =31 Short=0

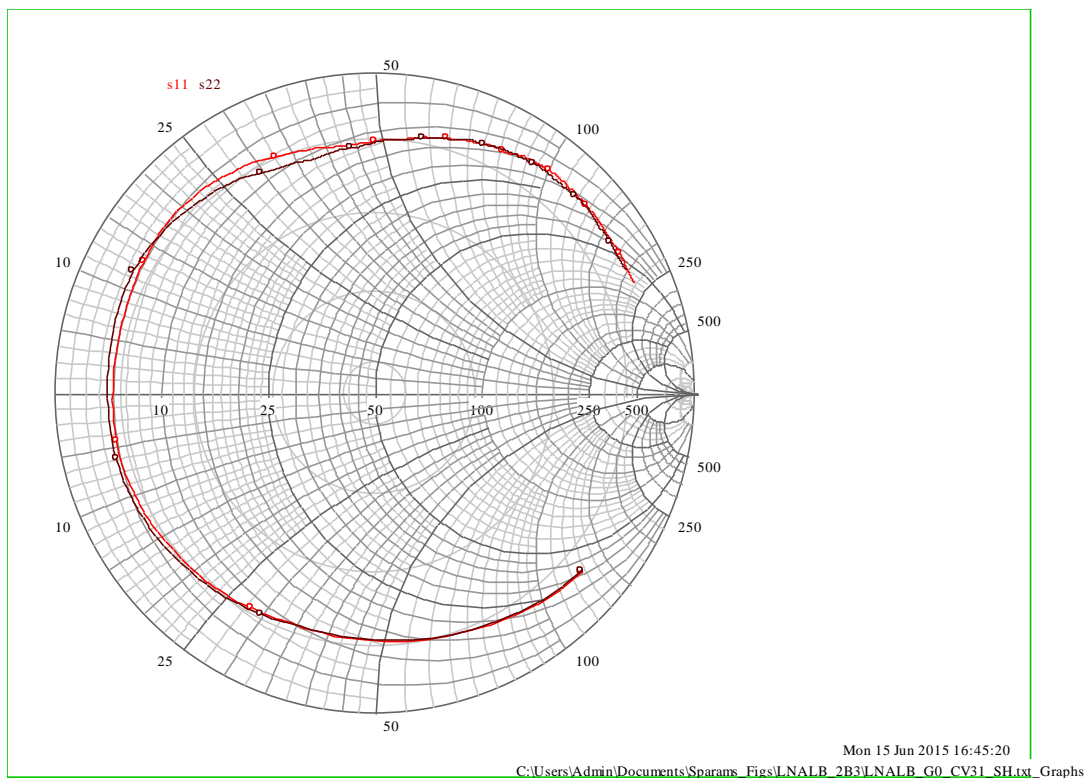


Figure 130 LNALB Sample=3 Gain=0, Cap_Var =31 Short=1

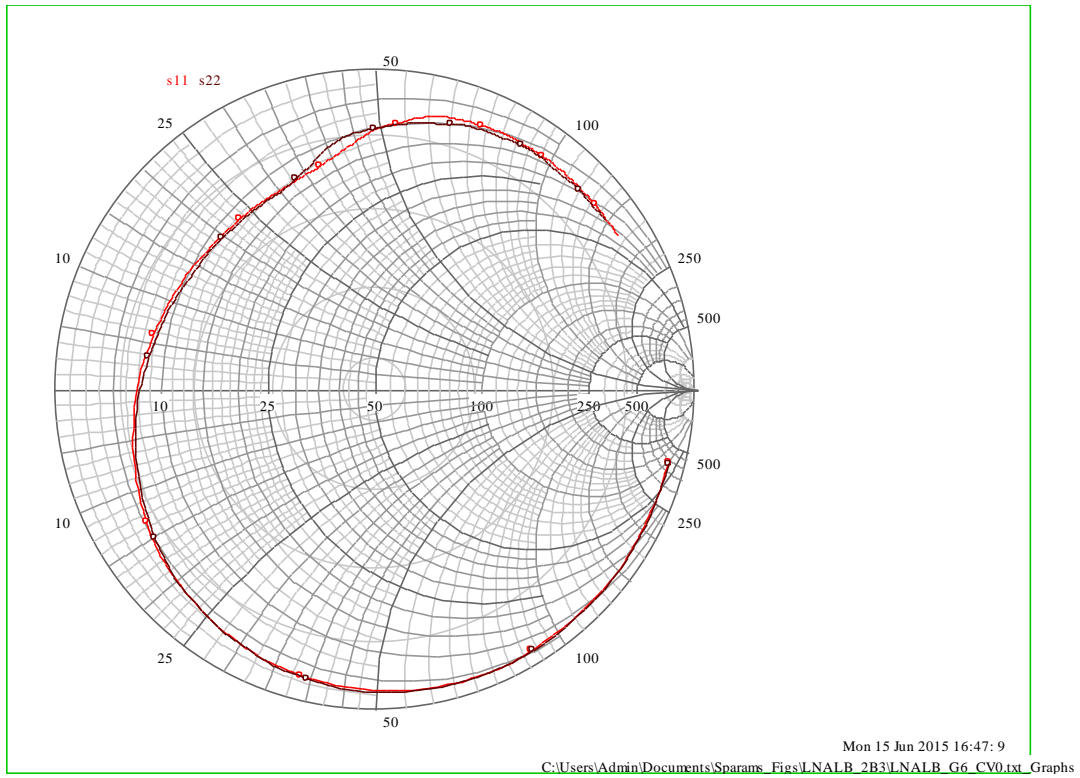


Figure 131 LNALB Sample=3 Gain=6, Cap_Var =0 Short=0

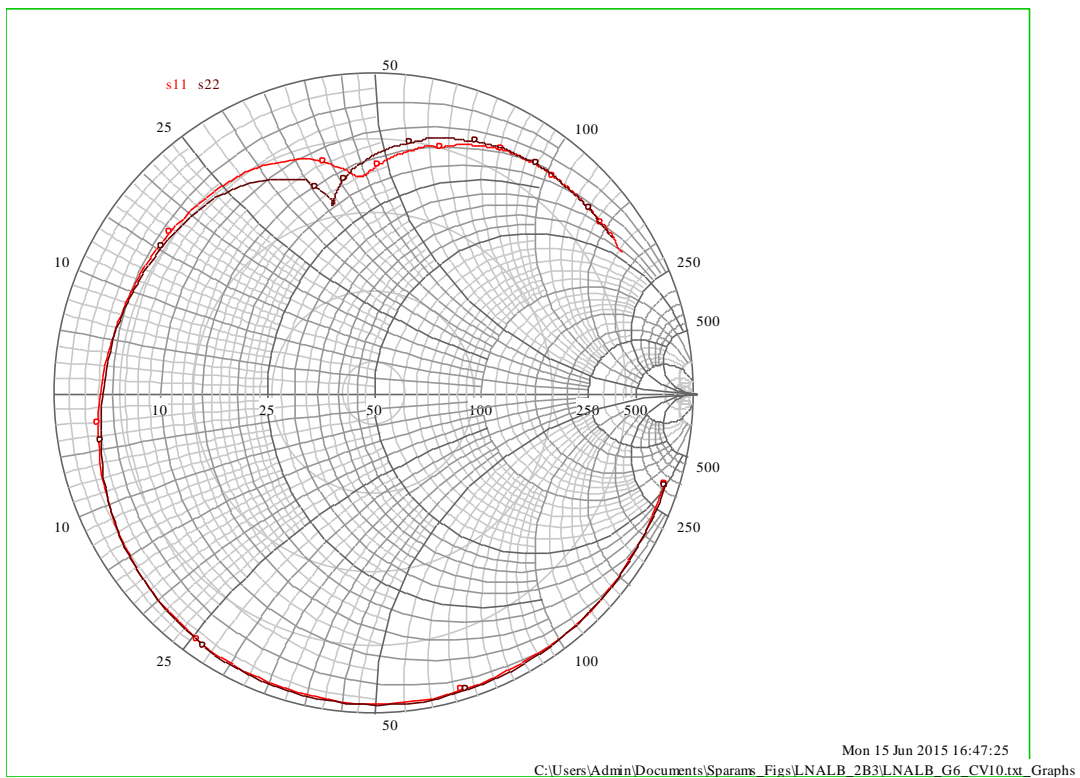


Figure 132 LNALB Sample=3 Gain=6, Cap_Var =10 Short=0

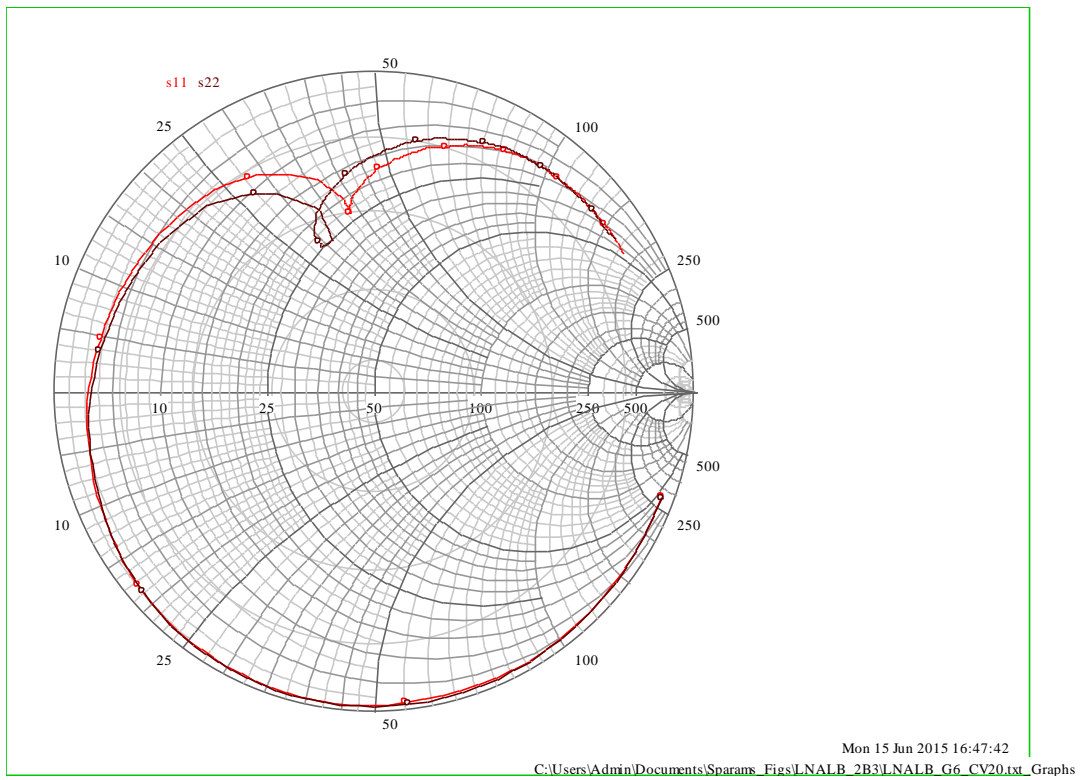


Figure 133 LNALB Sample=3 Gain=6, Cap_Var =20 Short=0

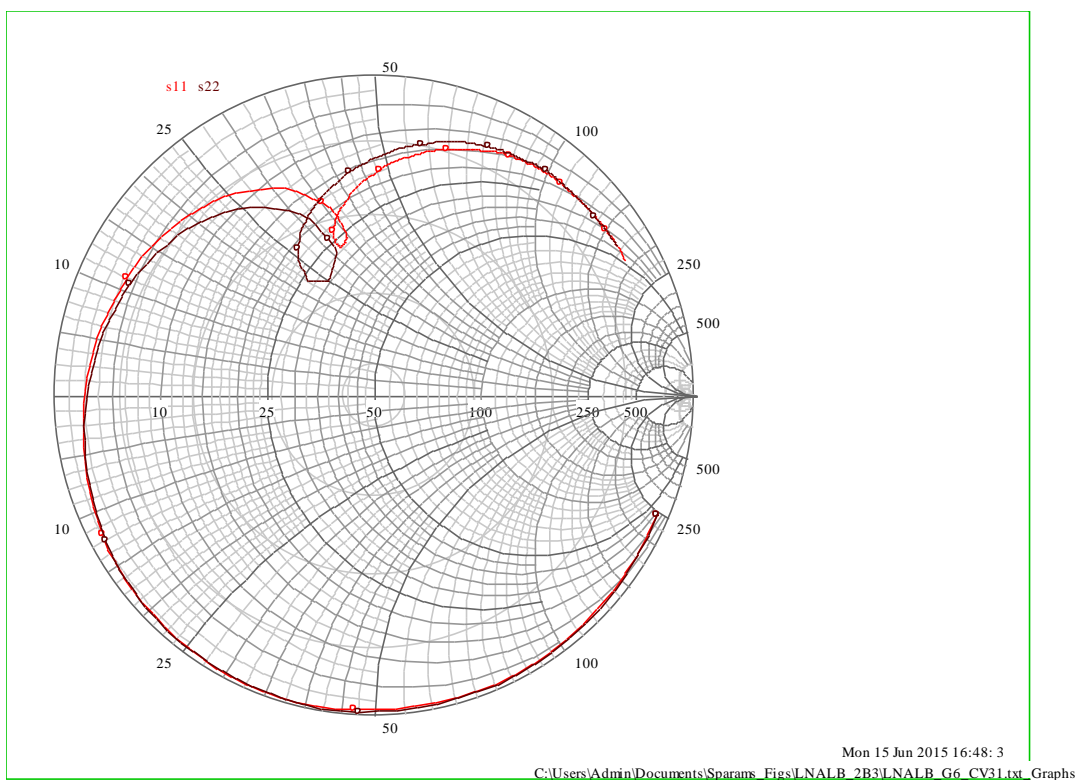


Figure 134 LNALB Sample=3 Gain=6, Cap_Var =31 Short=0

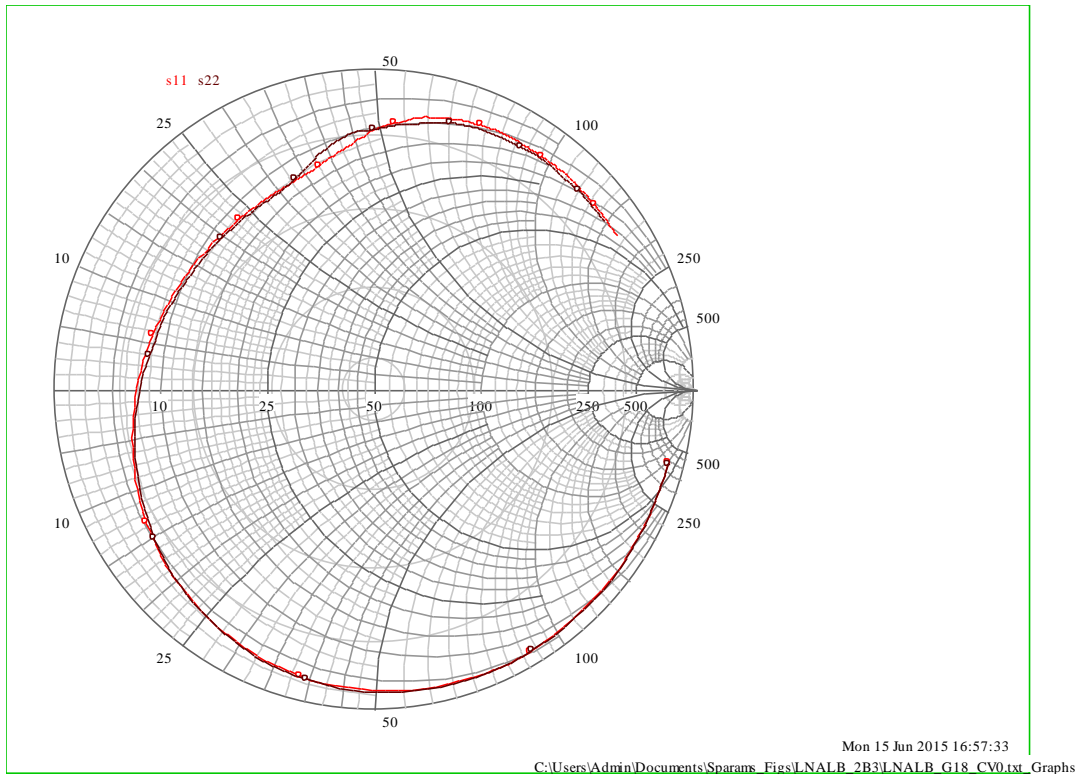


Figure 135 LNALB Sample=3 Gain=18, Cap_Var =0 Short=0

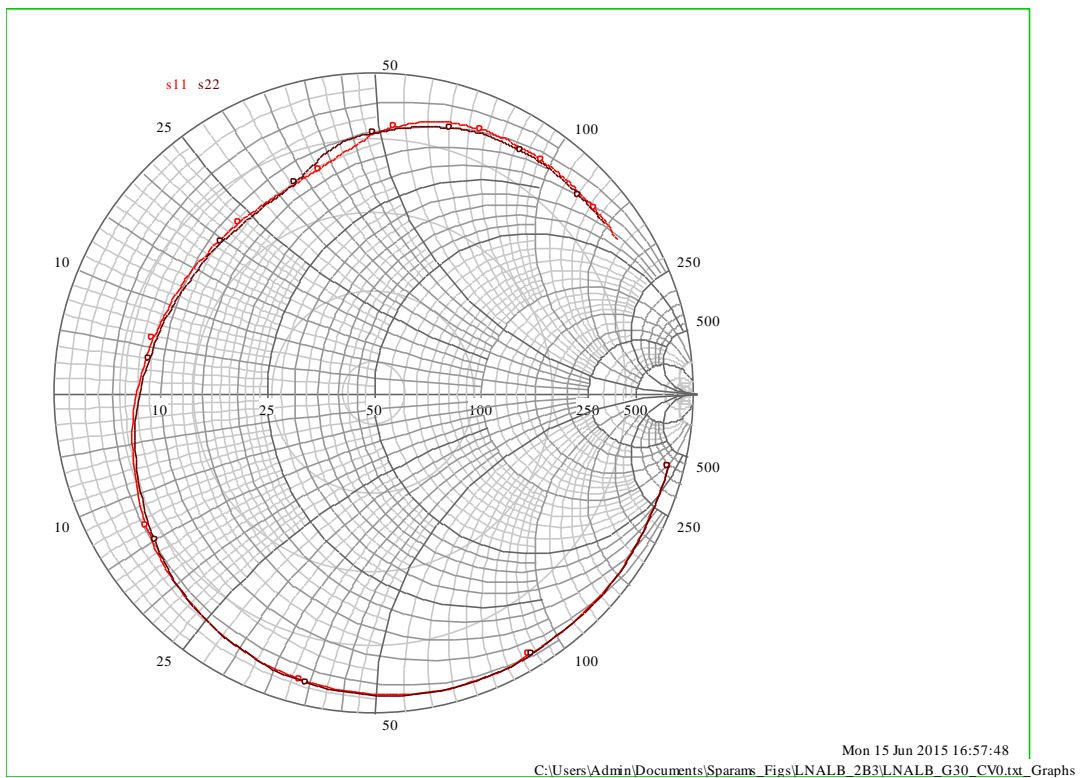


Figure 136 LNALB Sample=3 Gain=31, Cap_Var =0 Short=0

4.12 LNAW Channel A Sample 1

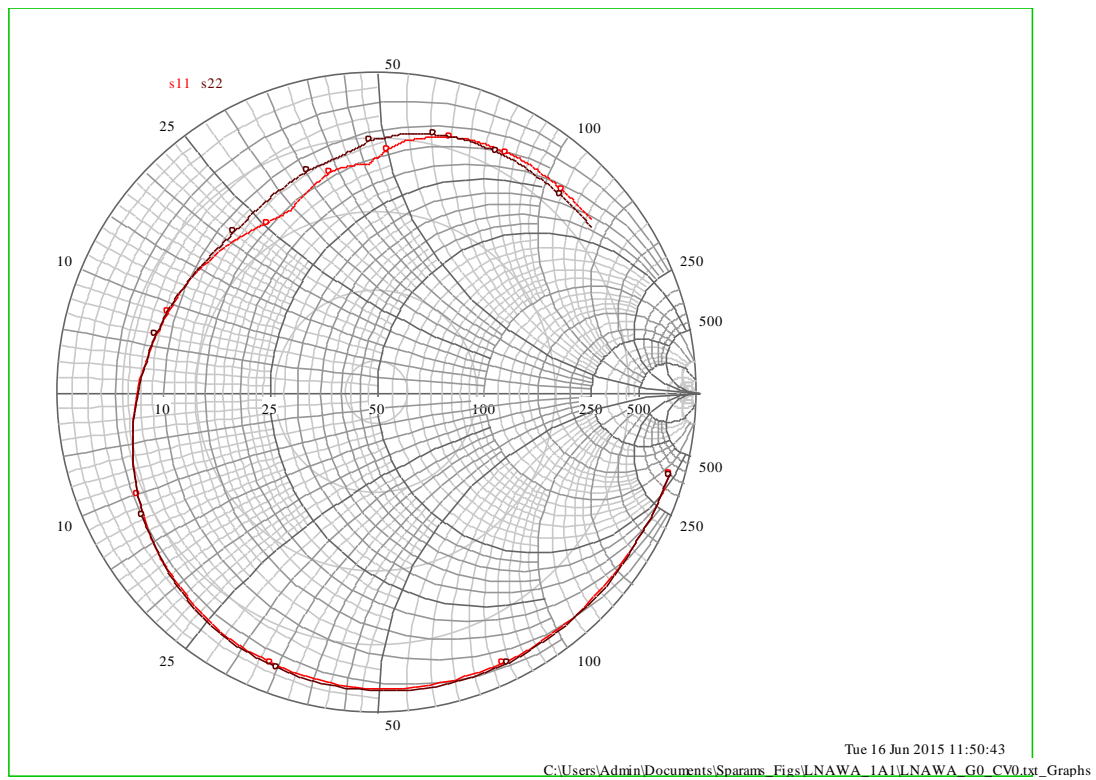


Figure 137 LNAWA Sample=1 Gain=0, Cap_Var=0 Short=0

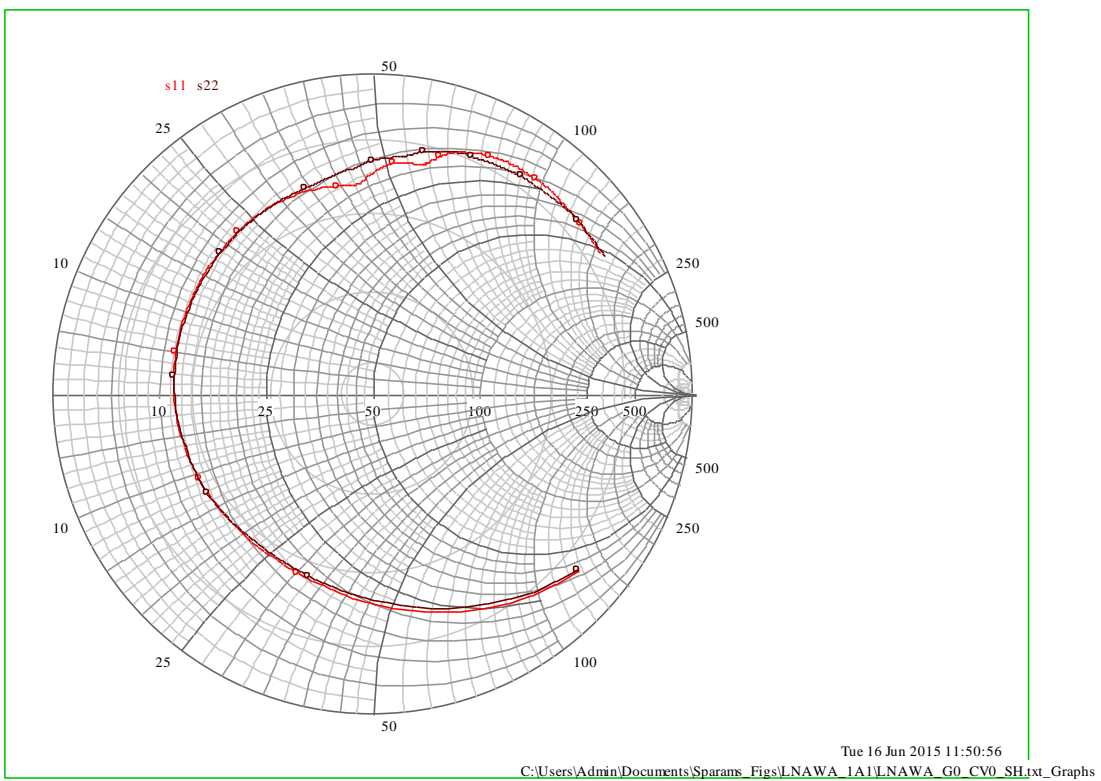


Figure 138 LNAWA Sample=1 Gain=0, Cap_Var=0 Short=1

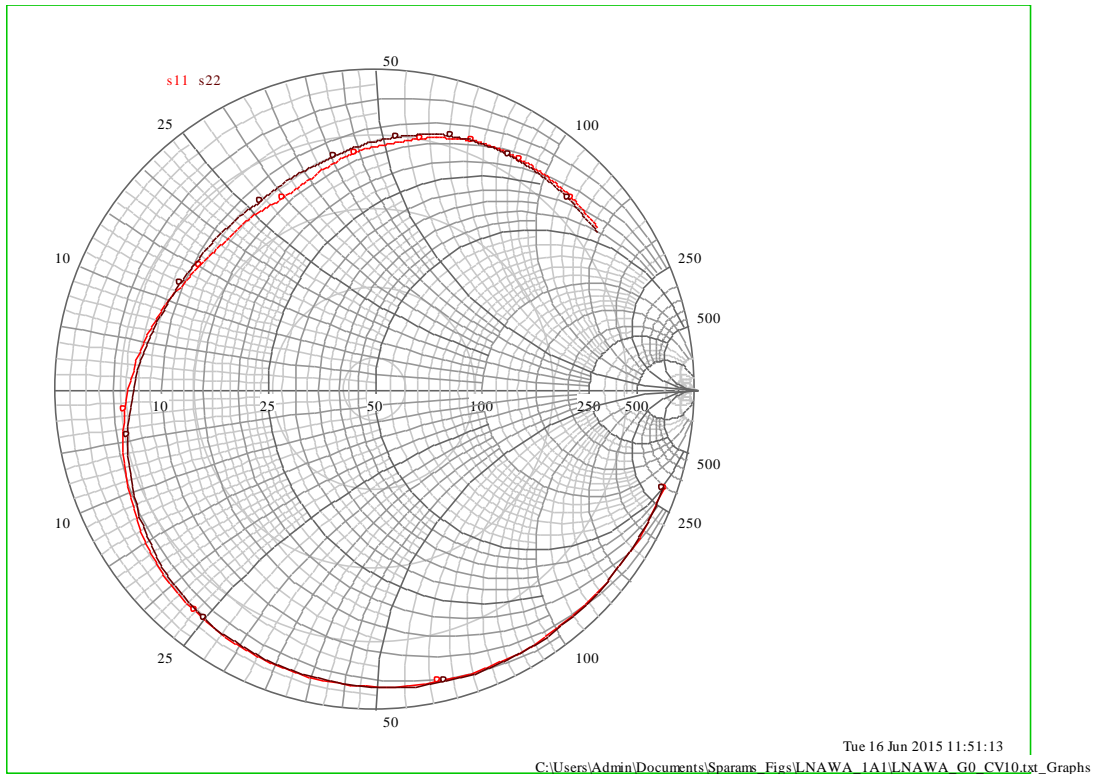


Figure 139 LNAWA Sample=1 Gain=0, Cap_Var =10 Short=0

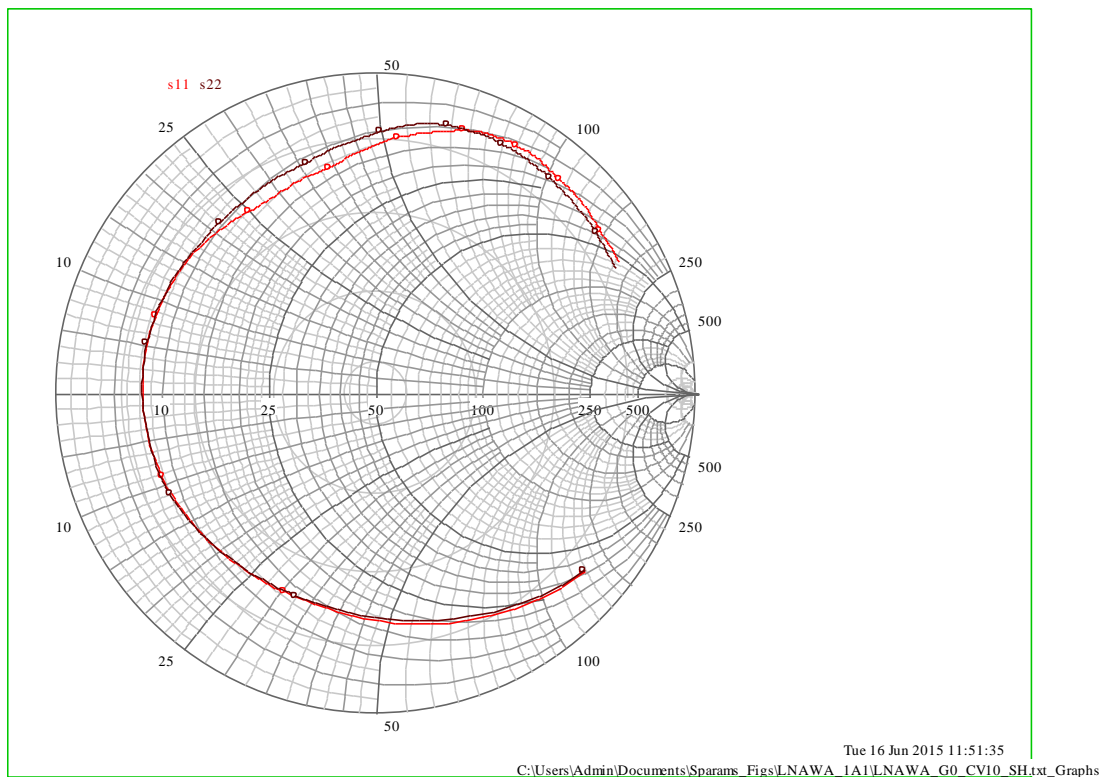


Figure 140 LNAWA Sample=1 Gain=0, Cap_Var =10 Short=1

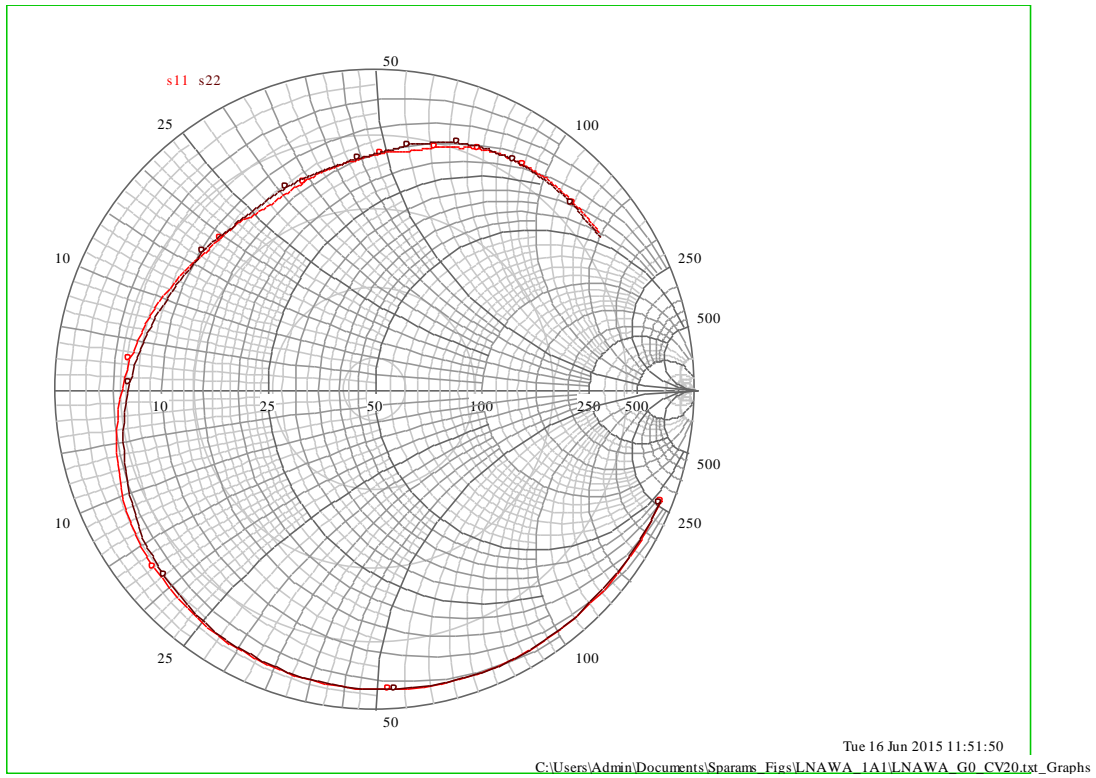


Figure 141 LNAWA Sample=1 Gain=0, Cap_Var =20 Short=0

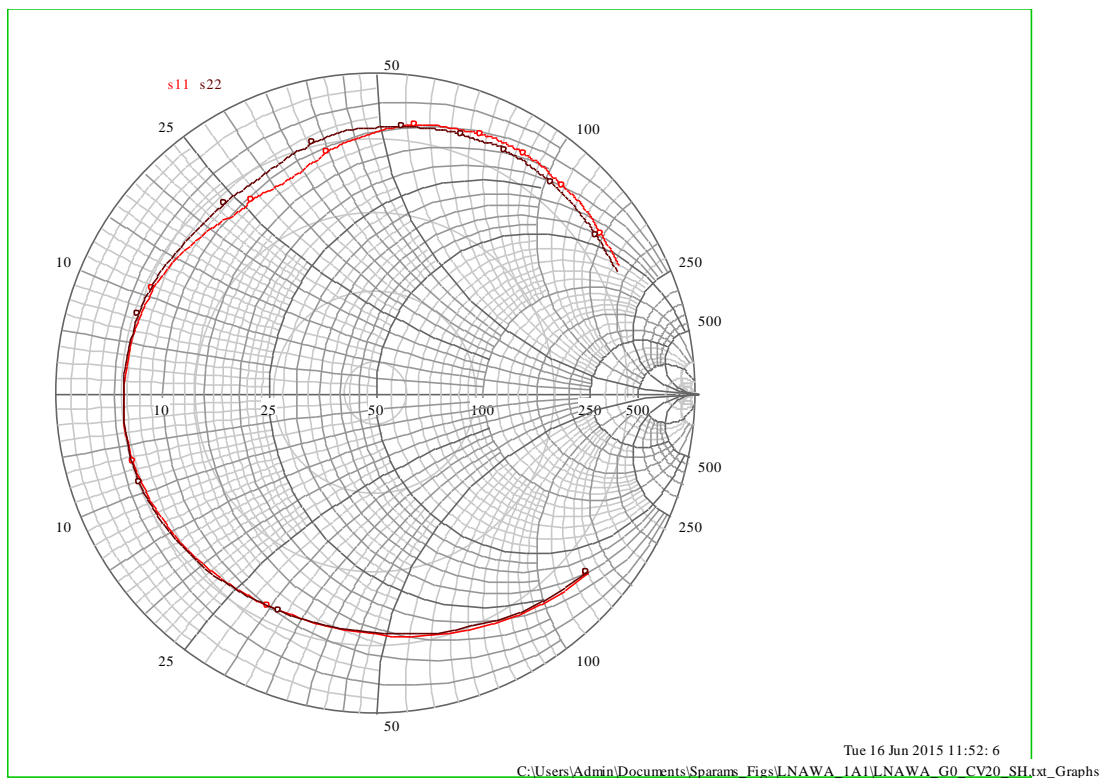


Figure 142 LNAWA Sample=1 Gain=0, Cap_Var =20 Short=1

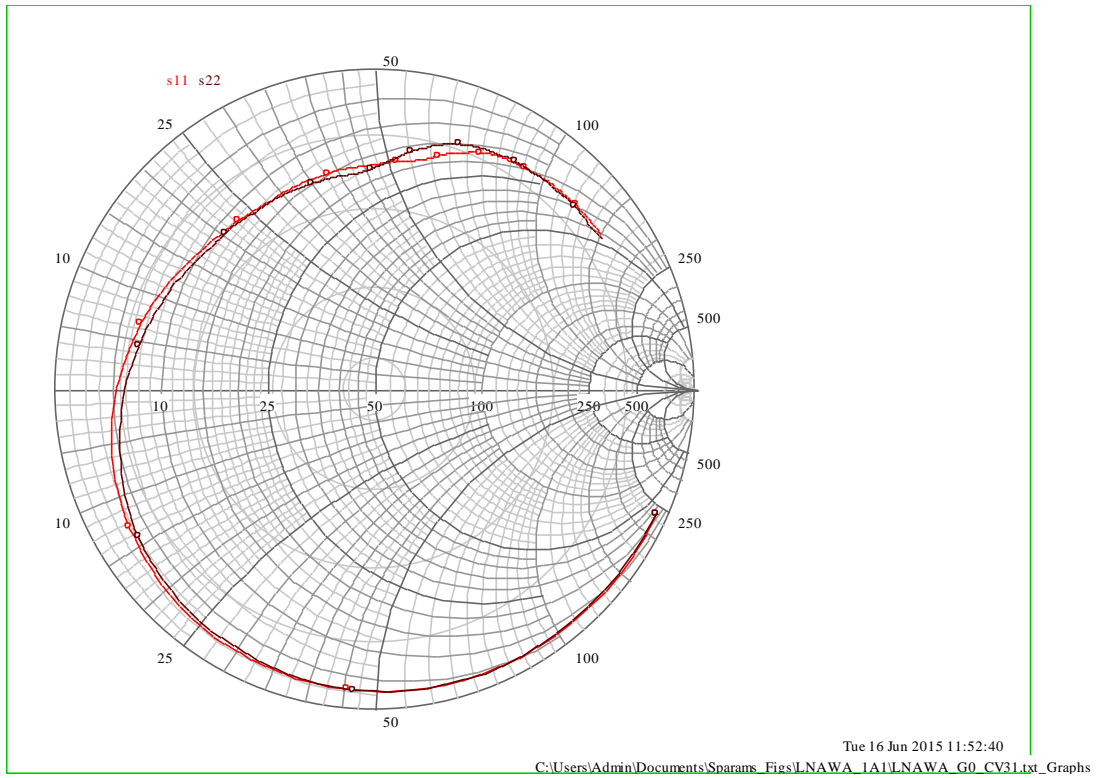


Figure 143 LNAWA Sample=1 Gain=0, Cap_Var =31 Short=0

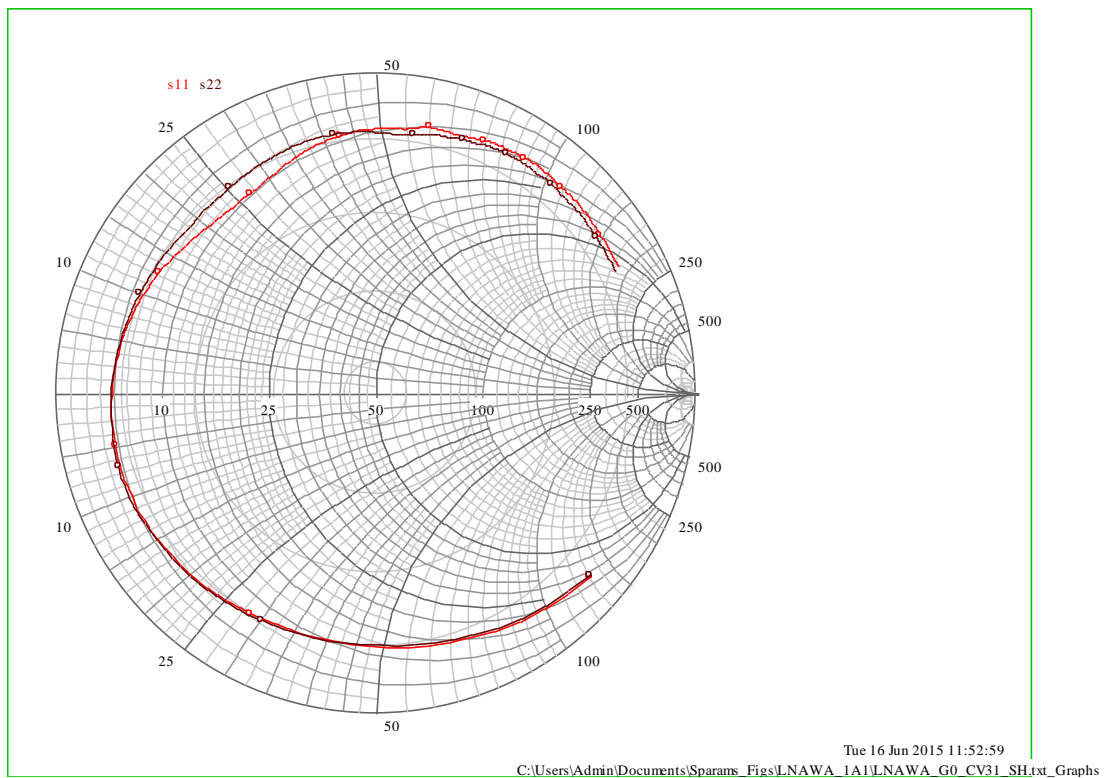


Figure 144 LNAWA Sample=1 Gain=0, Cap_Var =31 Short=1

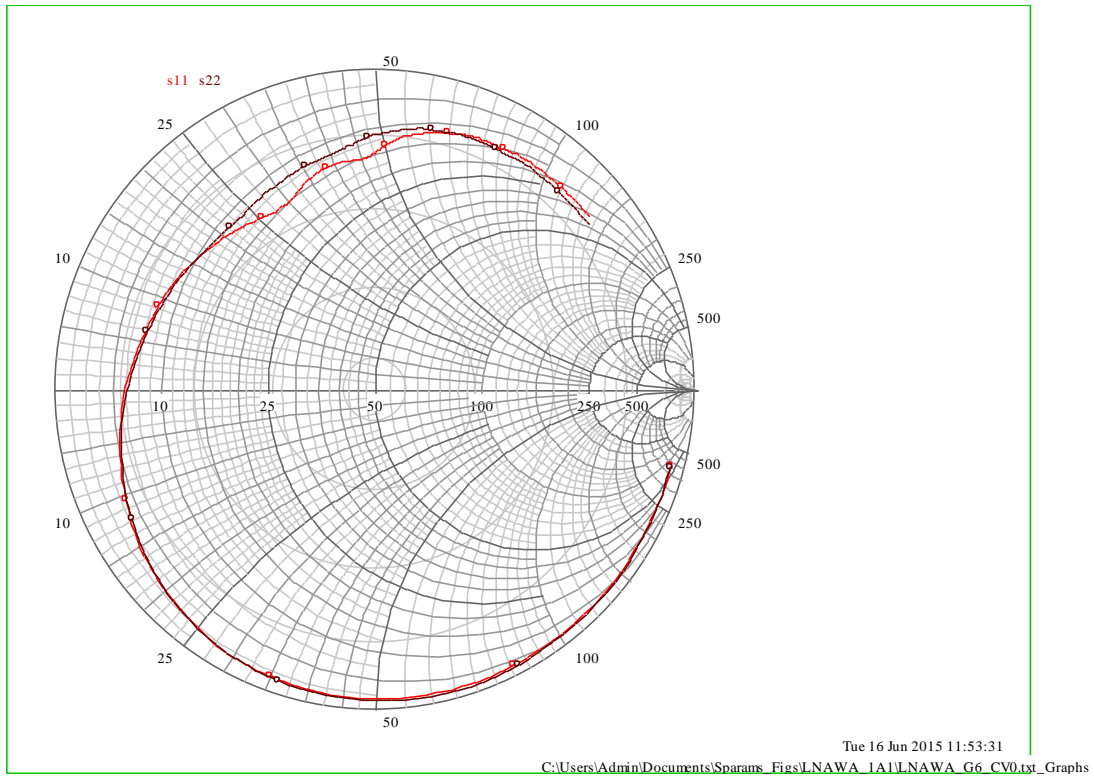


Figure 145 LNWA Sample=1 Gain=6, Cap_Var =0 Short=0

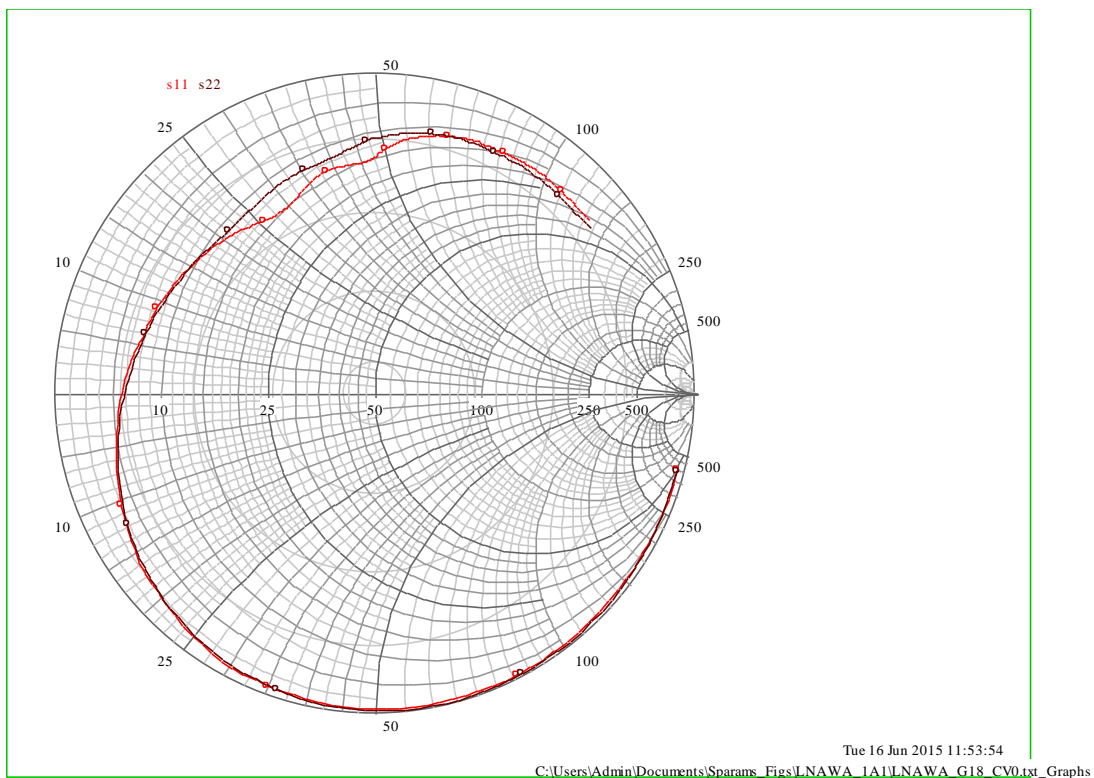


Figure 146 LNWA Sample=1 Gain=18, Cap_Var =0 Short=0

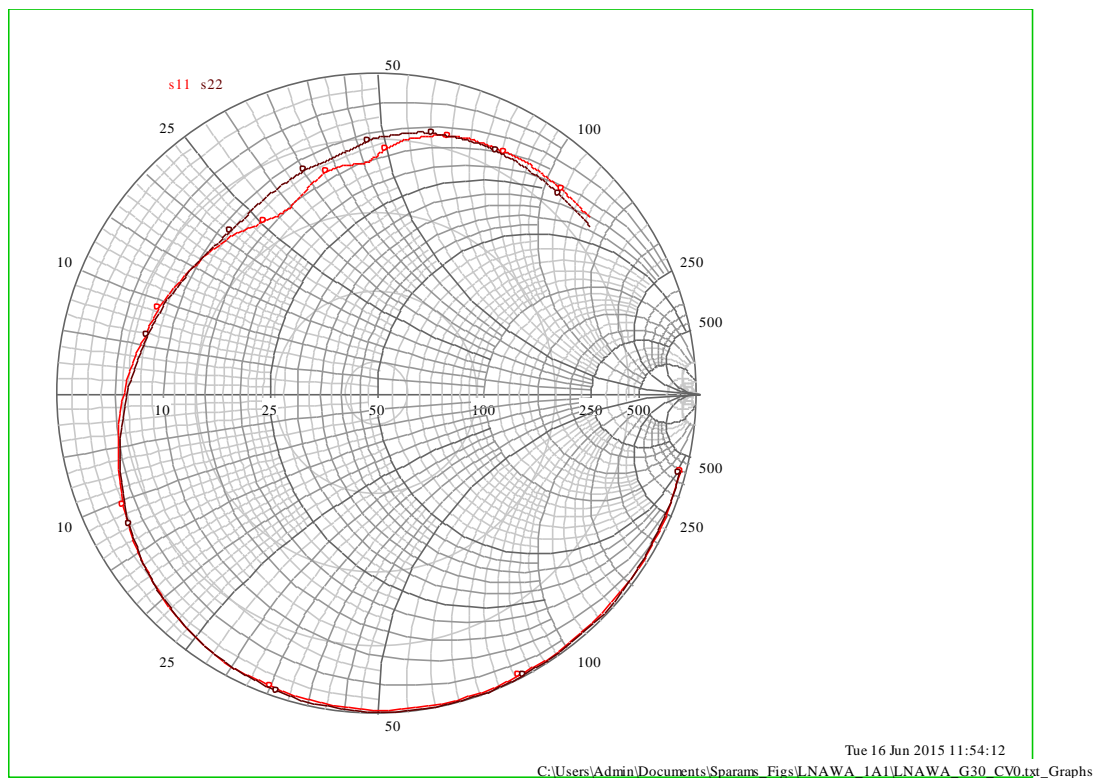


Figure 147 LNAWA Sample=1 Gain=31, Cap_Var =0 Short=0

4.13 LNAW Channel A Sample 2

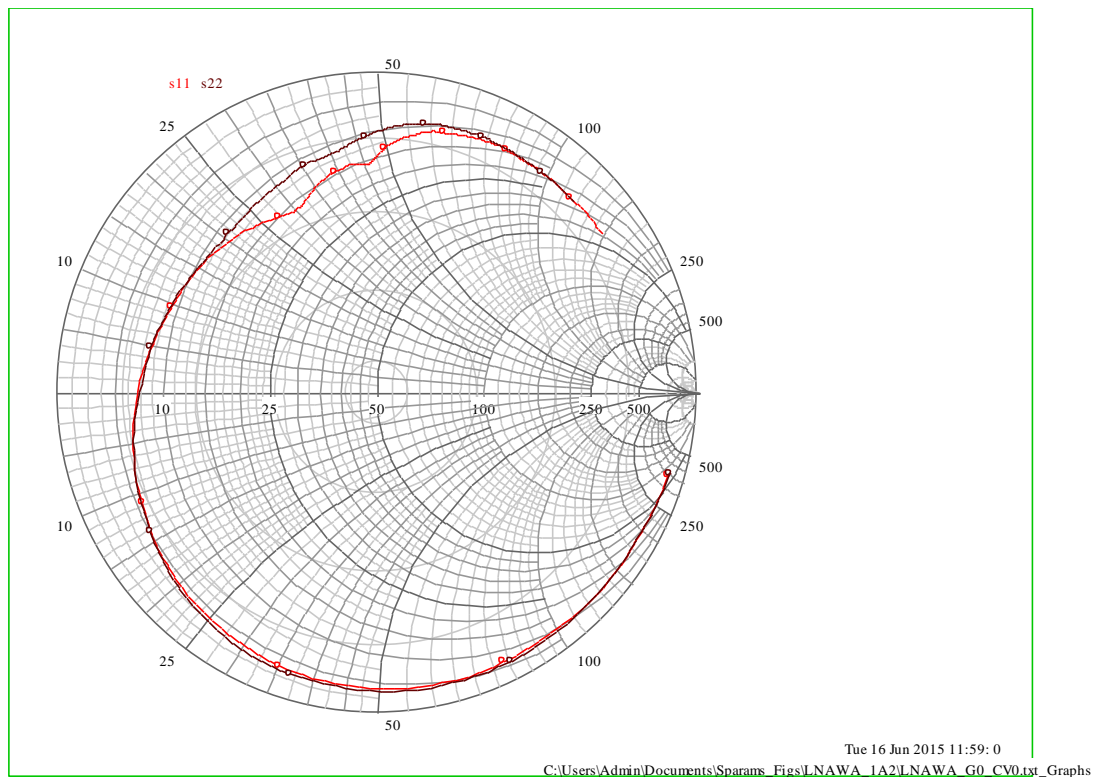


Figure 148 LNAWA Sample=2 Gain=0, Cap_Var=0 Short=0

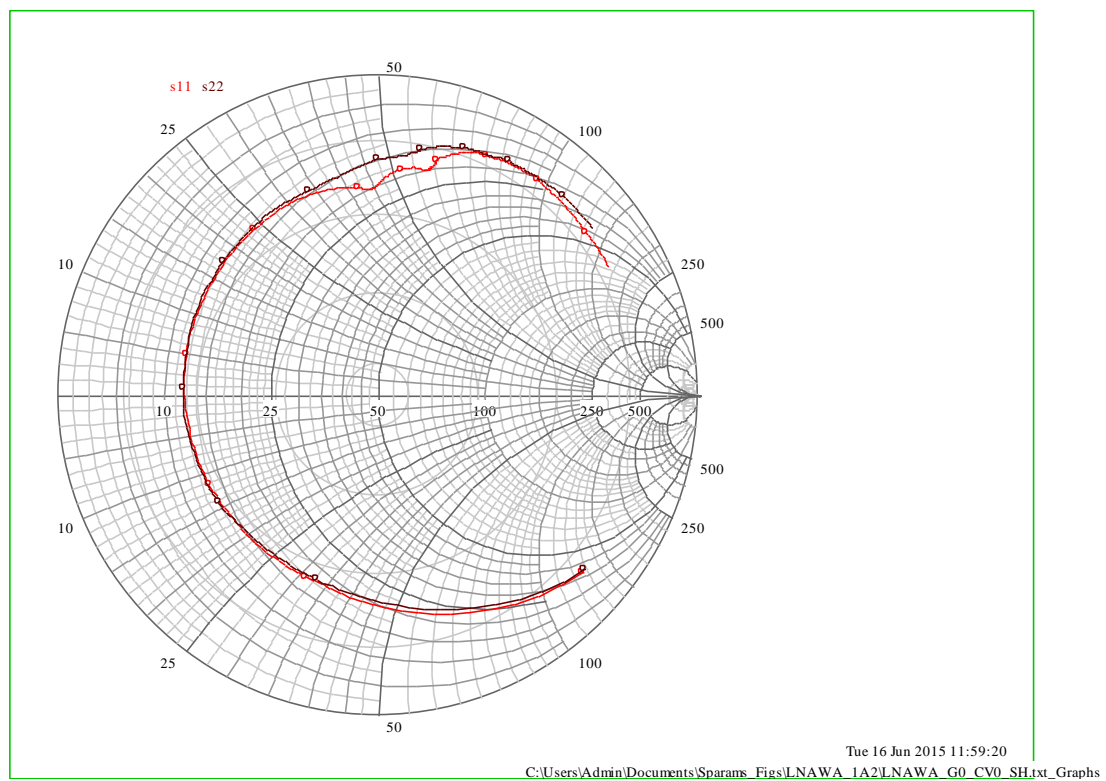
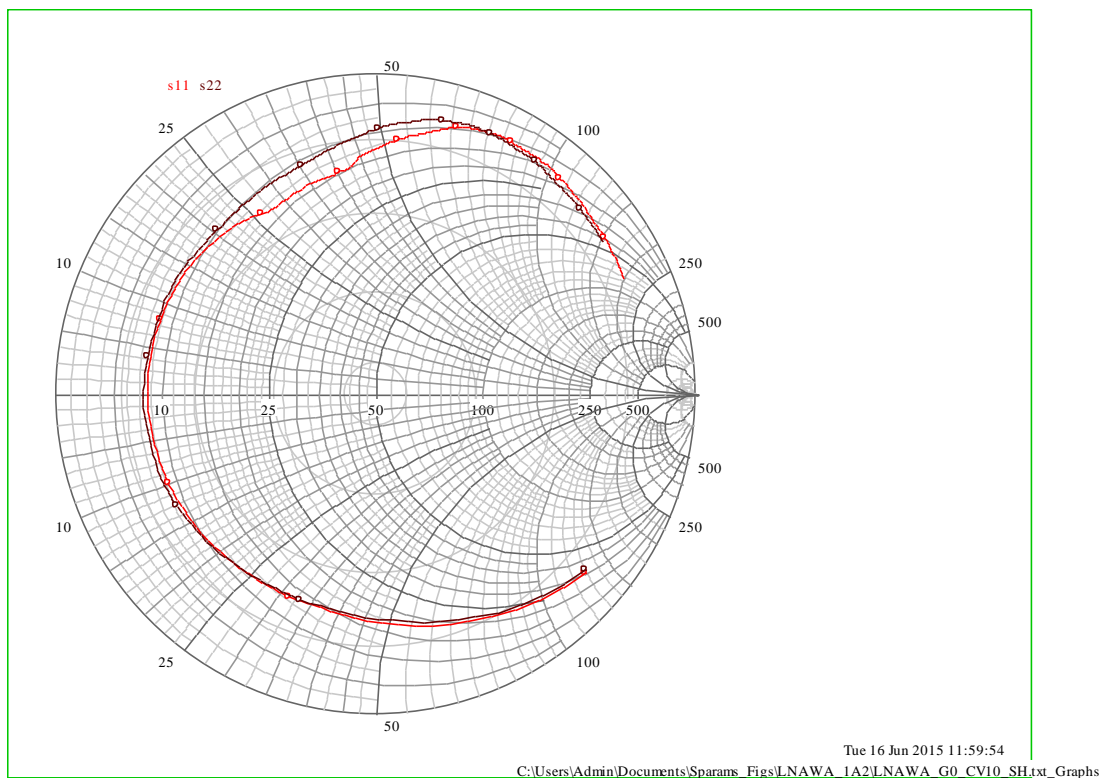
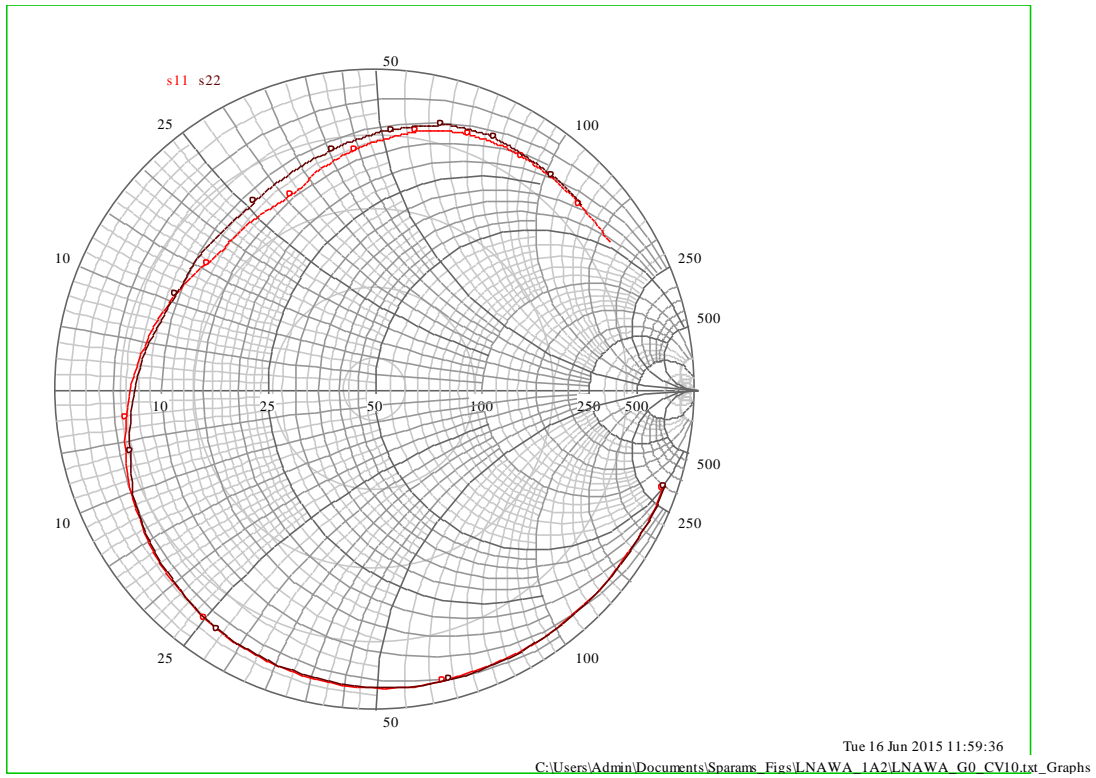
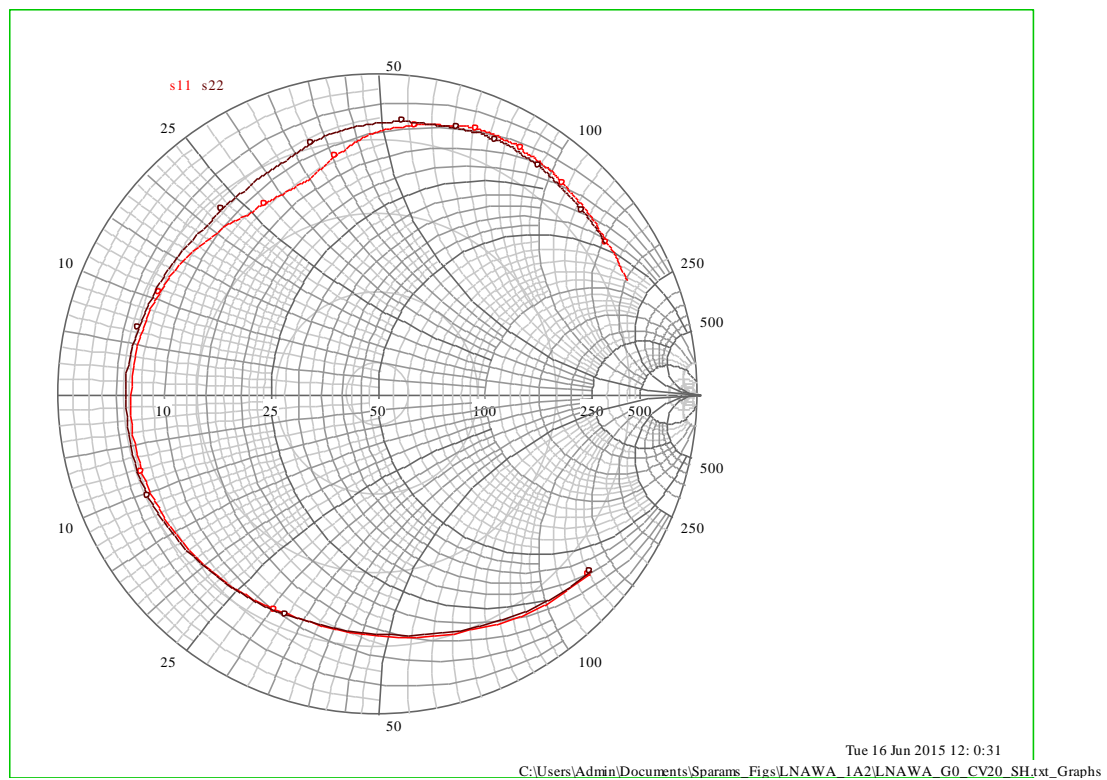
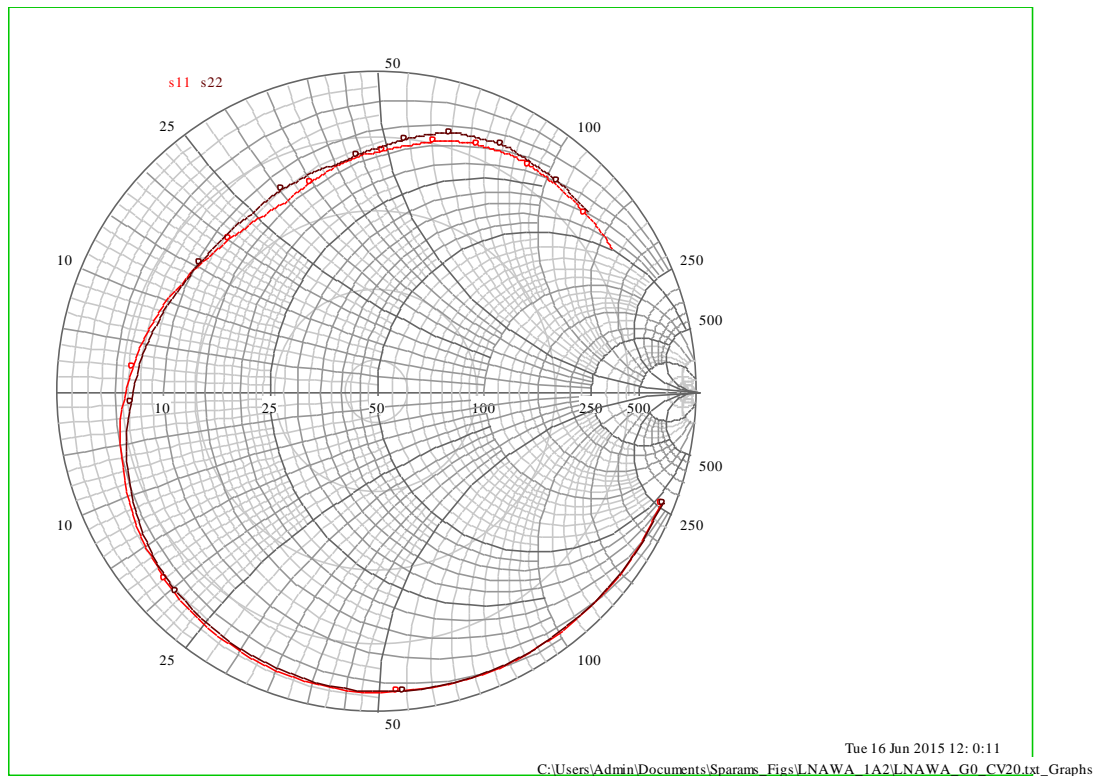


Figure 149 LNAWA Sample=2 Gain=0, Cap_Var=0 Short=1





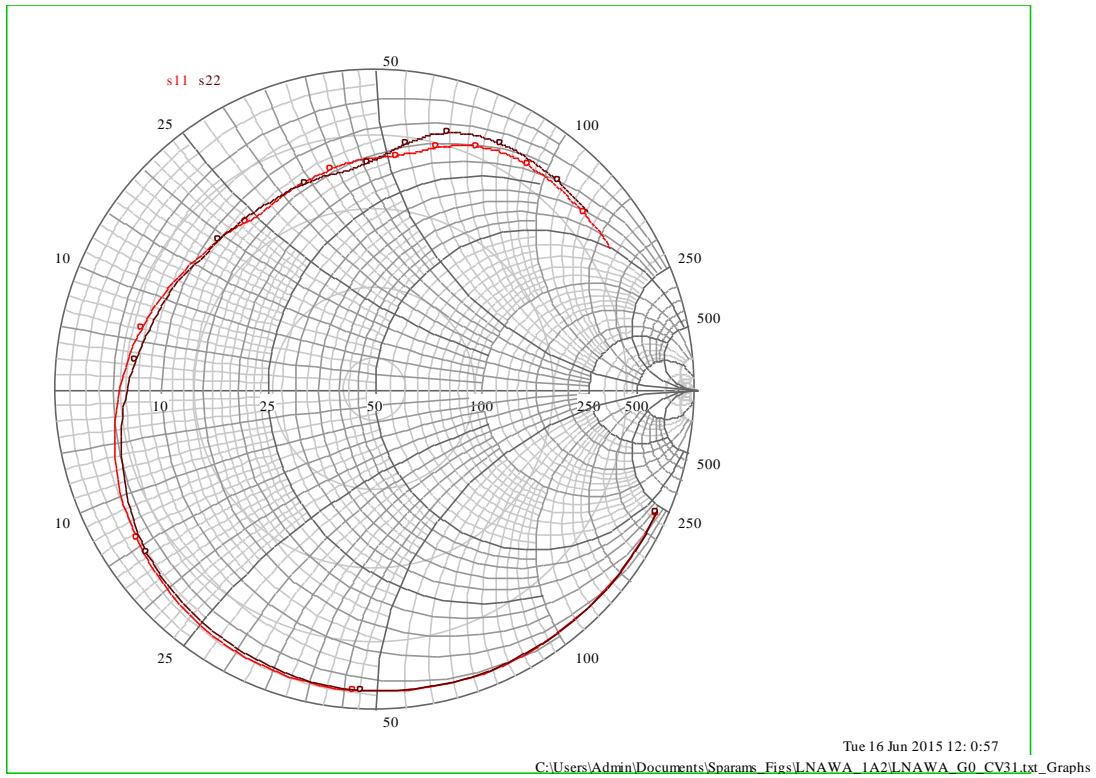


Figure 154 LNAWA Sample=2 Gain=0, Cap_Var =31 Short=0

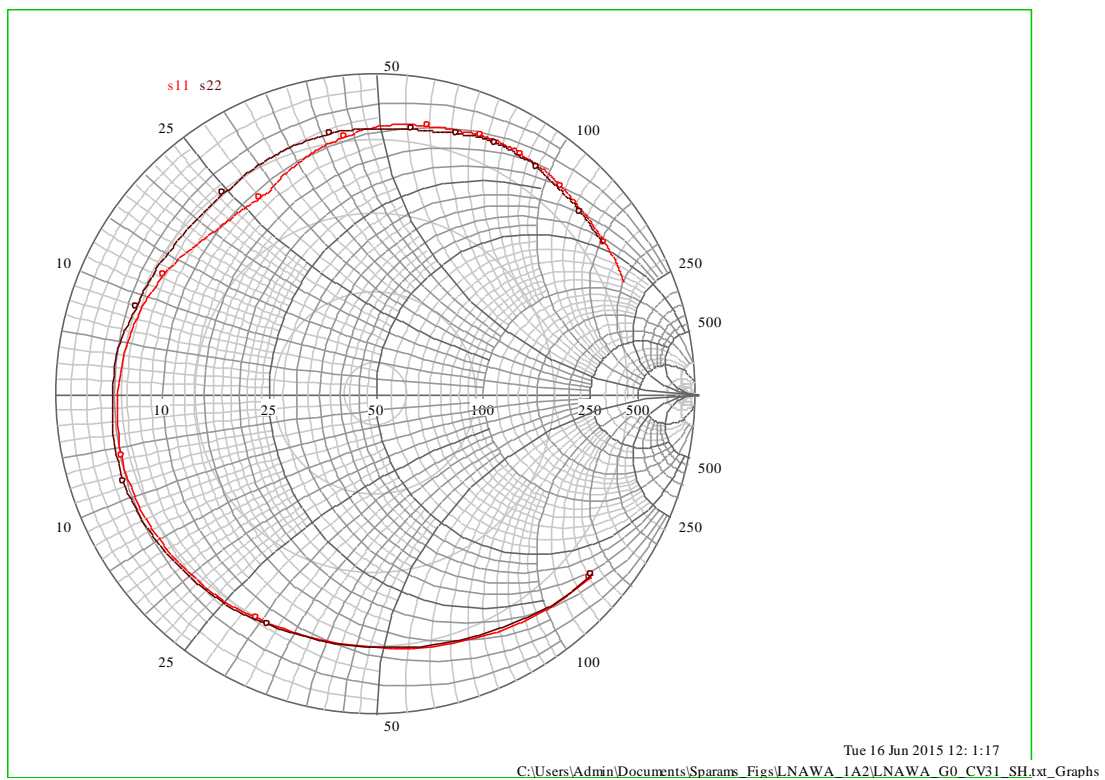
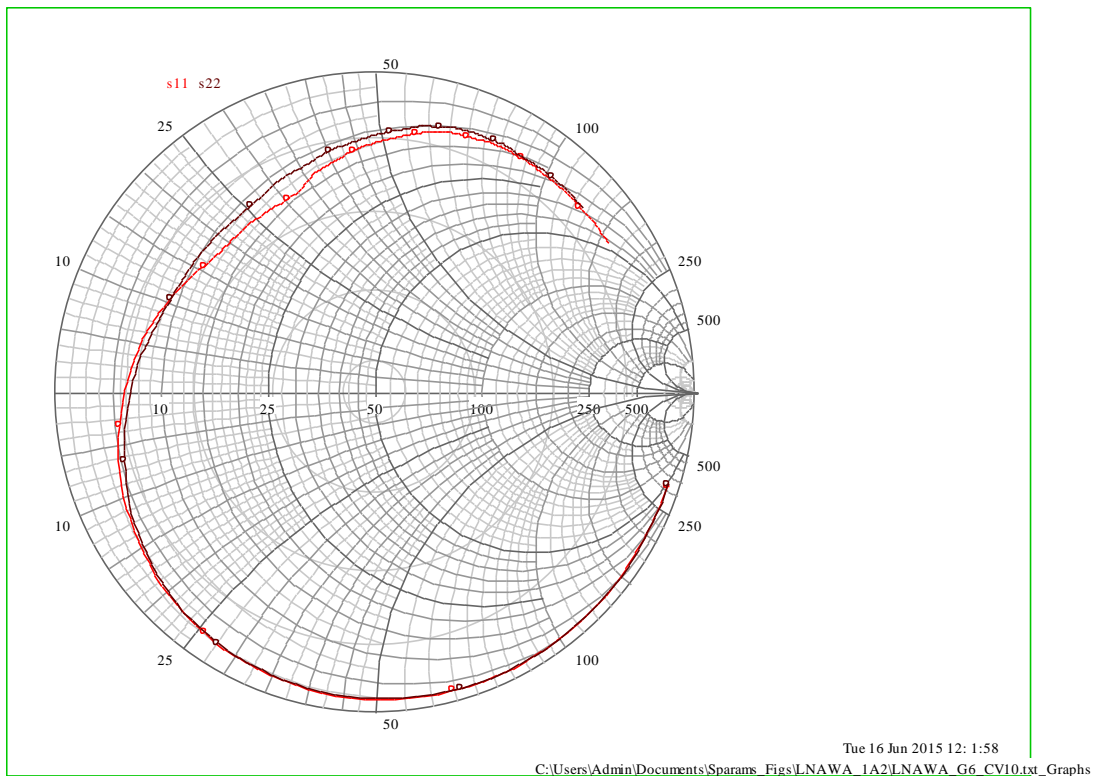
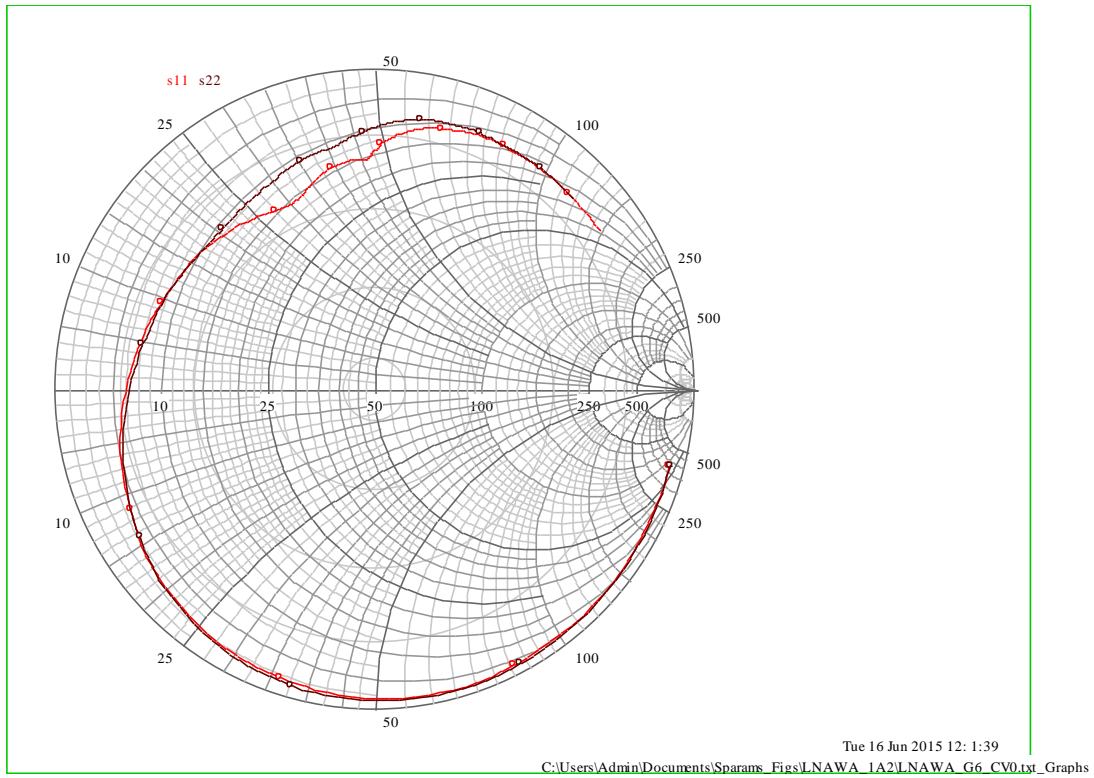


Figure 155 LNAWA Sample=2 Gain=0, Cap_Var =31 Short=1



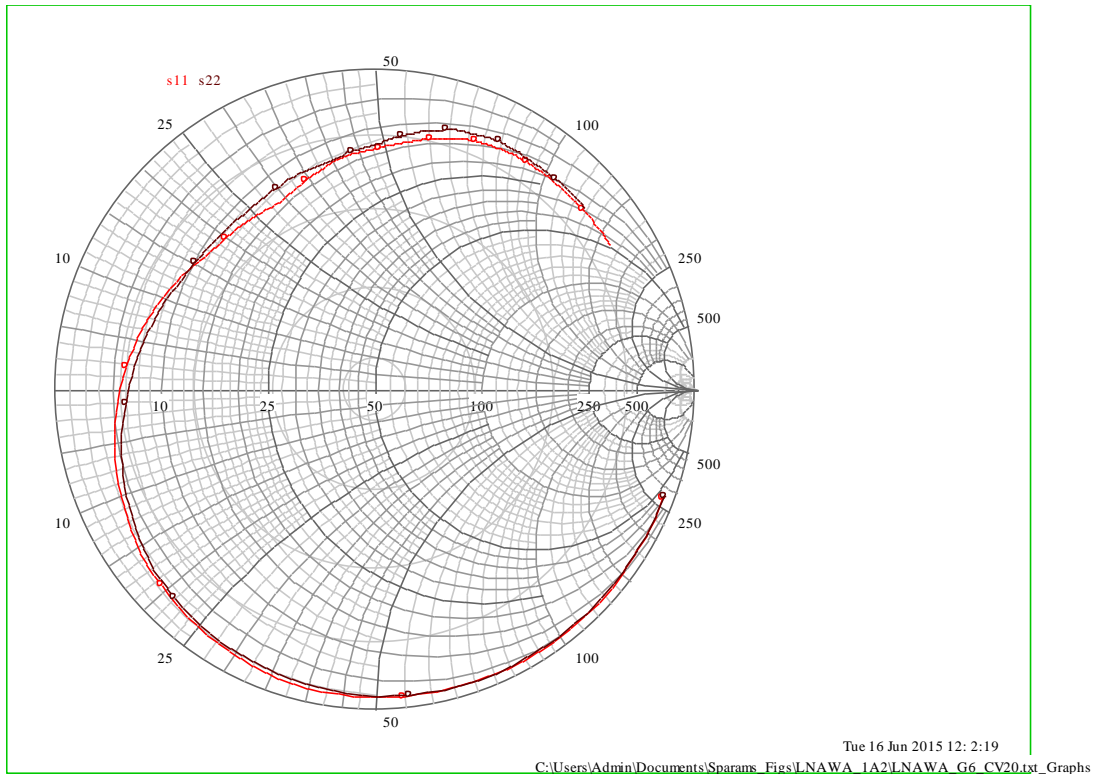


Figure 158 LNAWA Sample=2 Gain=6, Cap_Var =20 Short=0

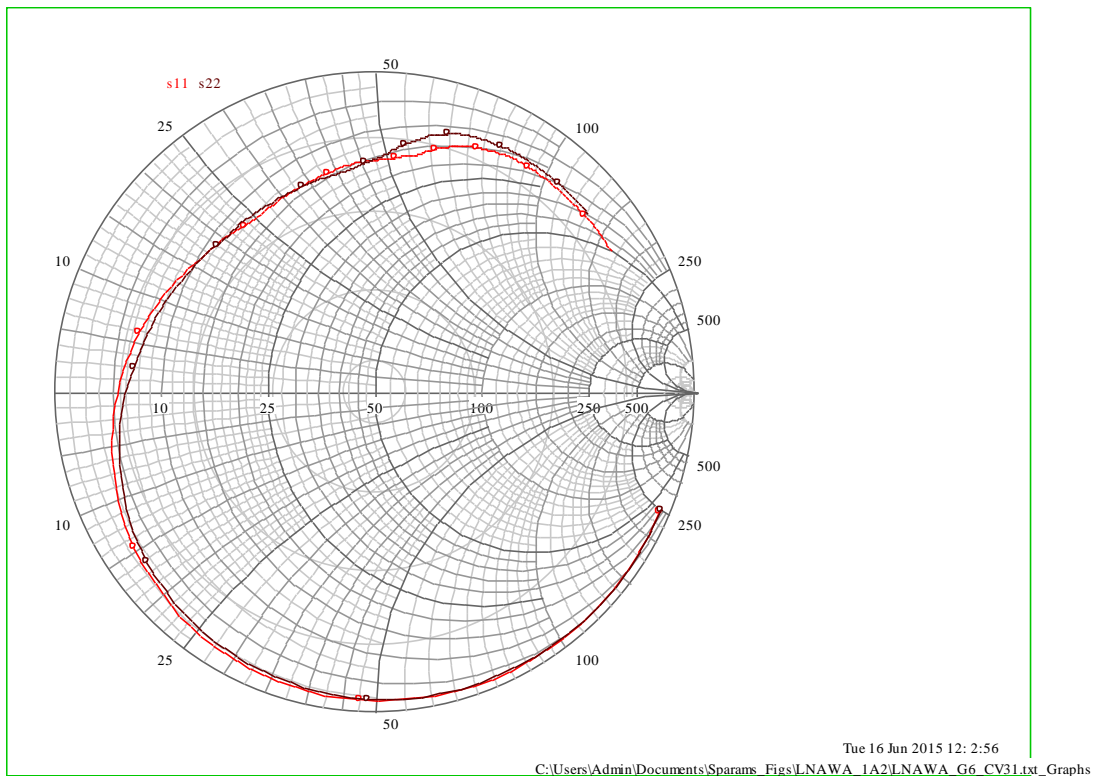


Figure 159 LNAWA Sample=2 Gain=6, Cap_Var =31 Short=0

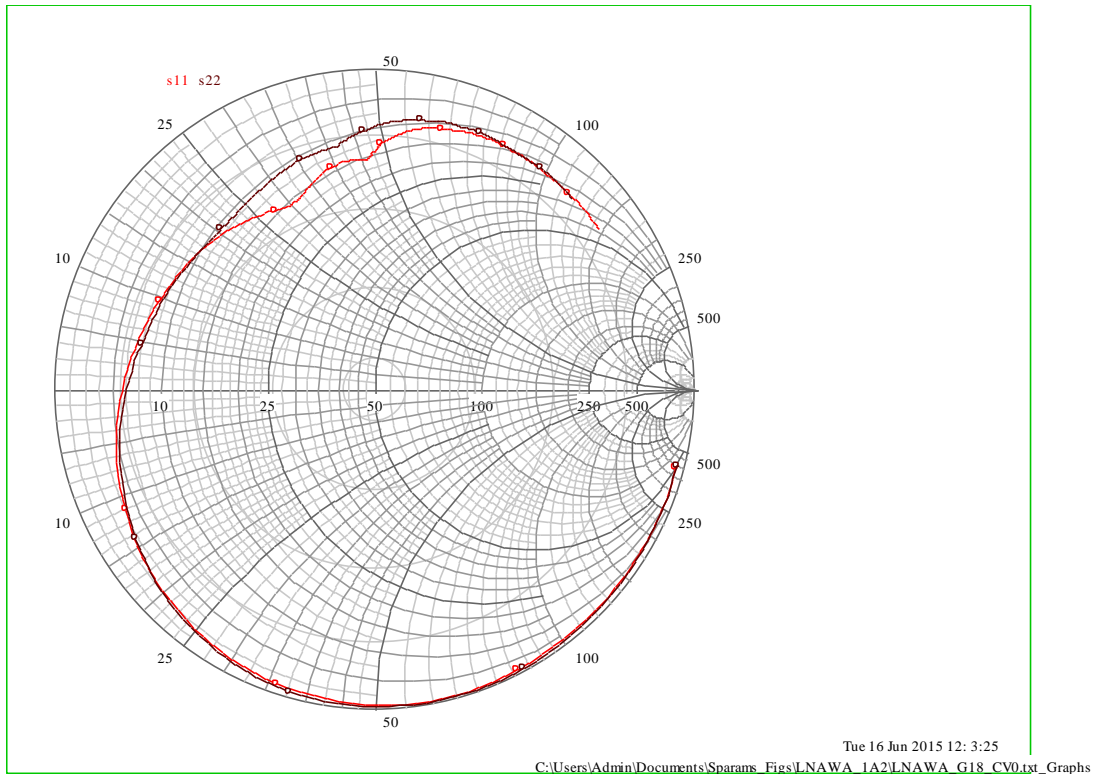


Figure 160 LNAWA Sample=2 Gain=18, Cap_Var =0 Short=0

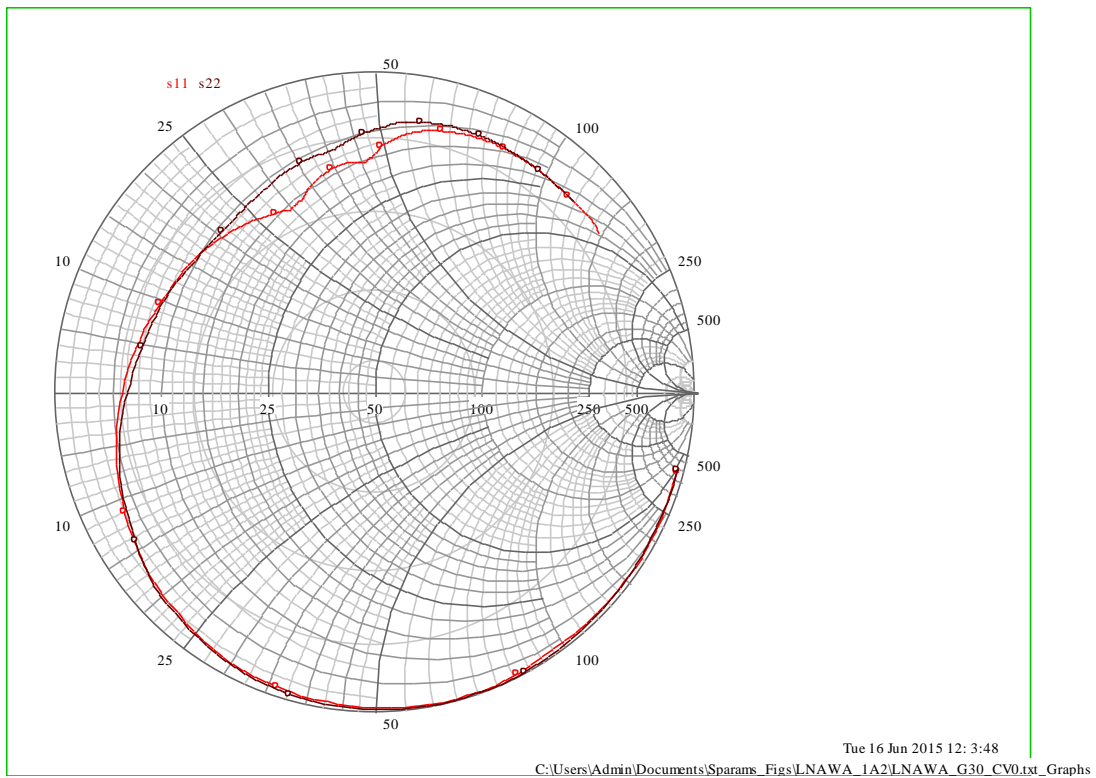


Figure 161 LNAWA Sample=2 Gain=31, Cap_Var =0 Short=0

4.14 LNAW Channel A Sample 3

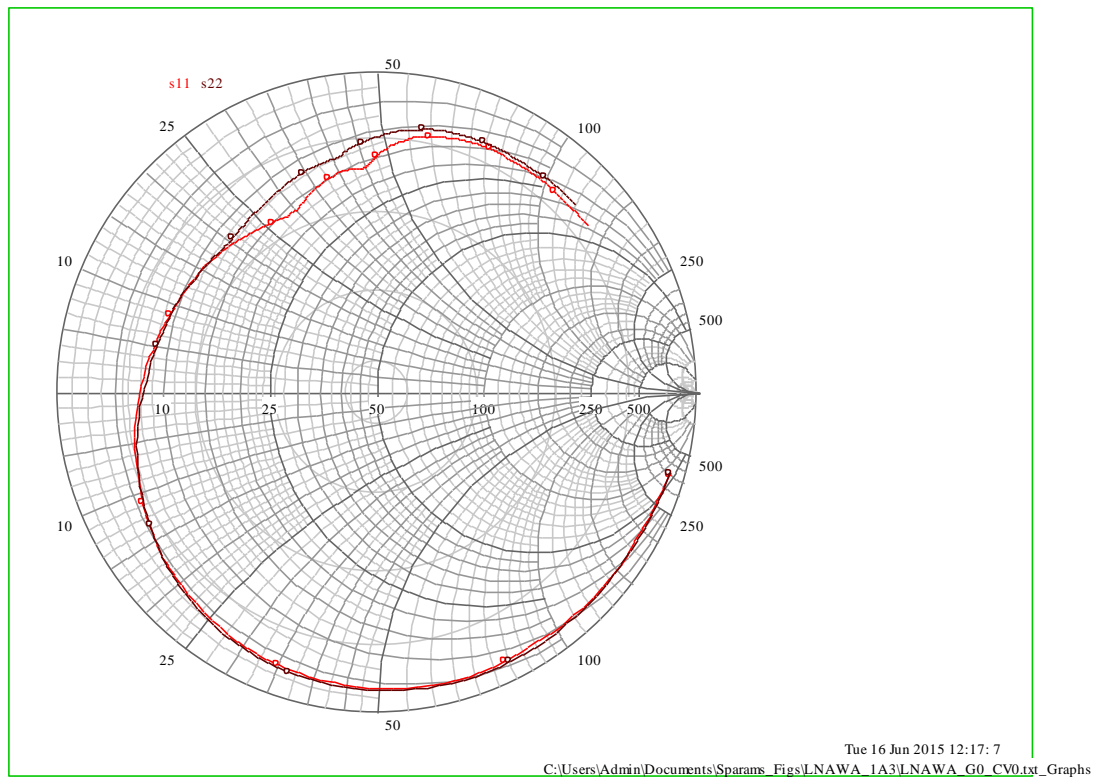


Figure 162 LNAWA Sample=3 Gain=0, Cap_Var=0 Short=0

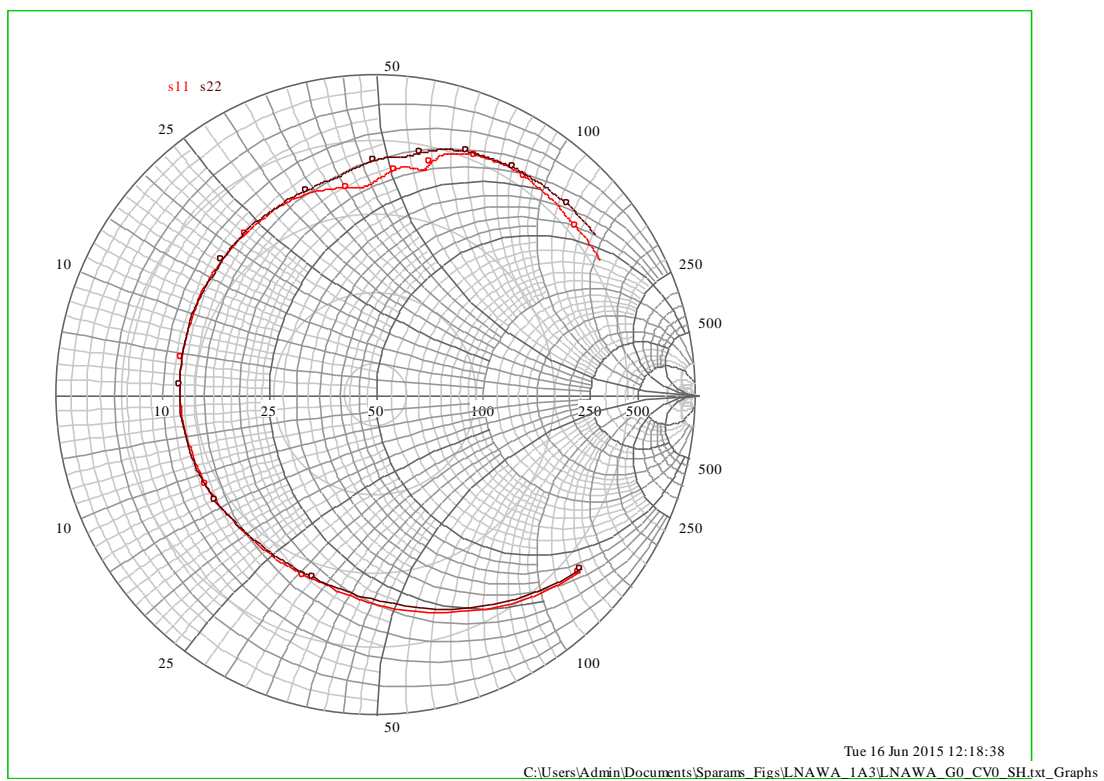
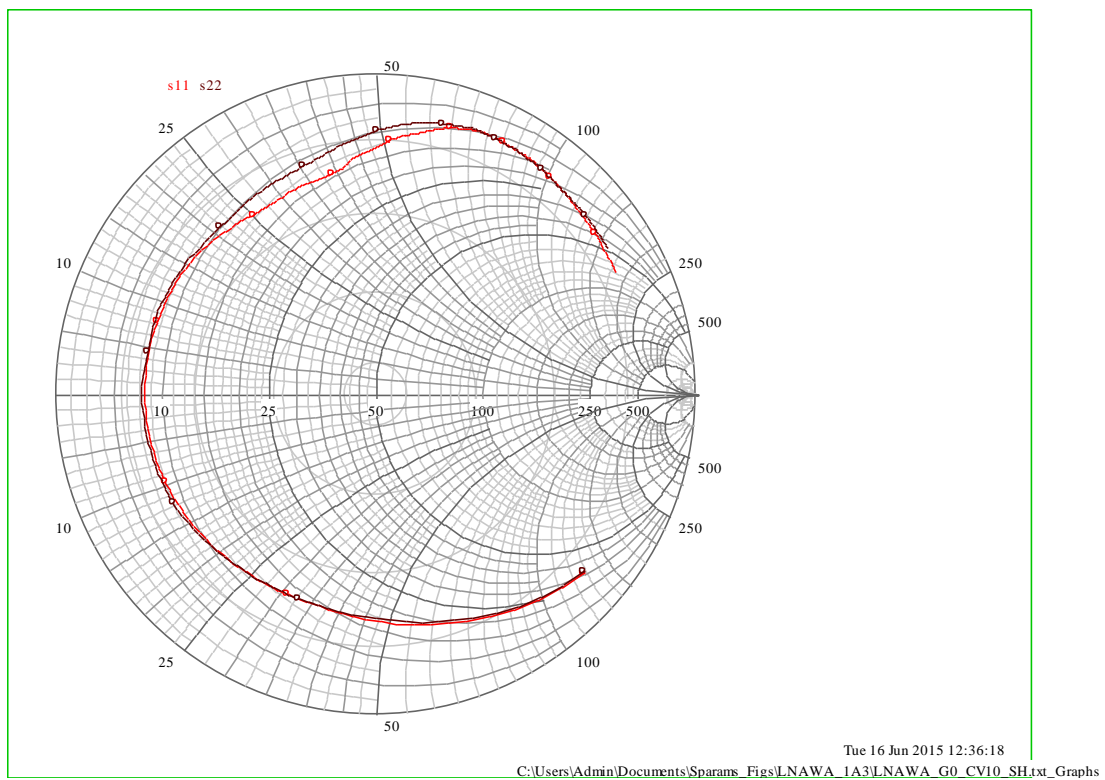
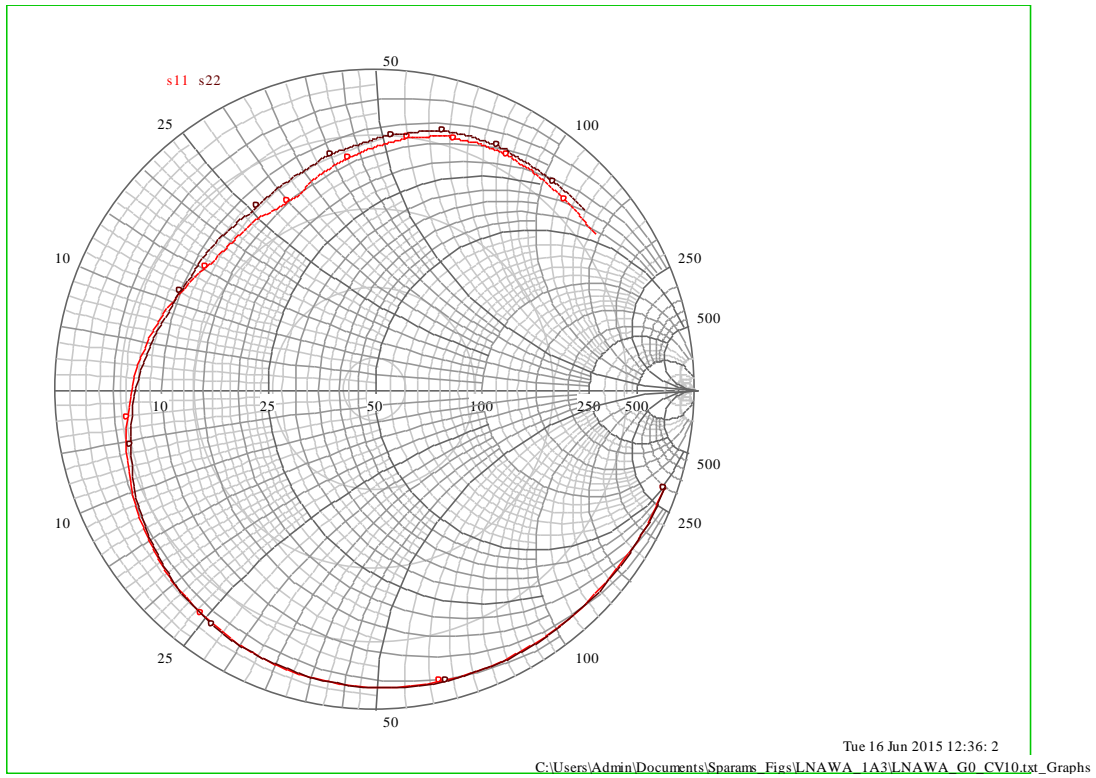


Figure 163 LNAWA Sample=3 Gain=0, Cap_Var=0 Short=1



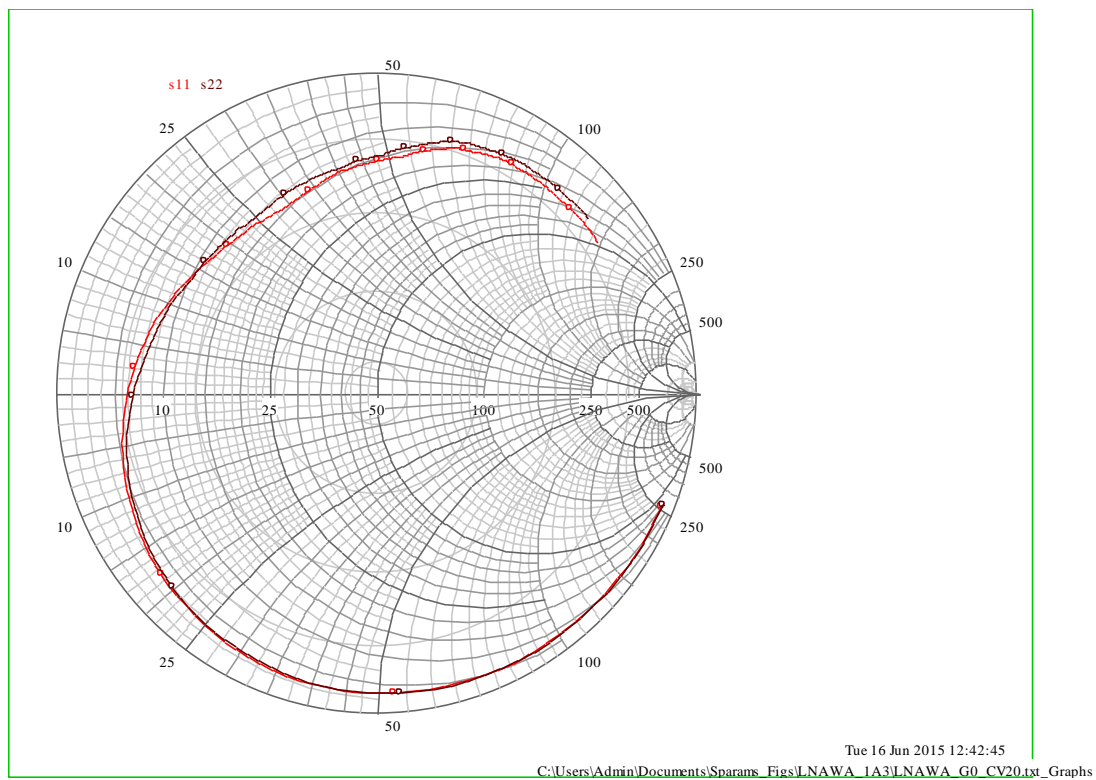


Figure 166 LNAWA Sample=3 Gain=0, Cap_Var =20 Short=0

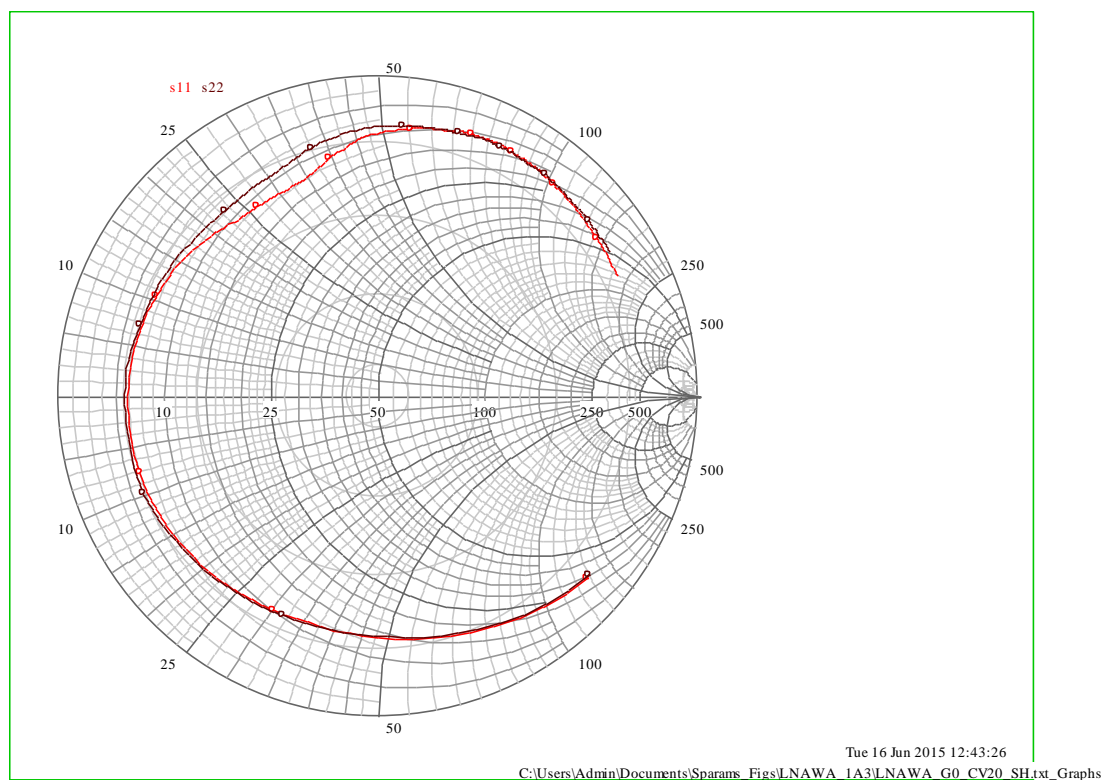
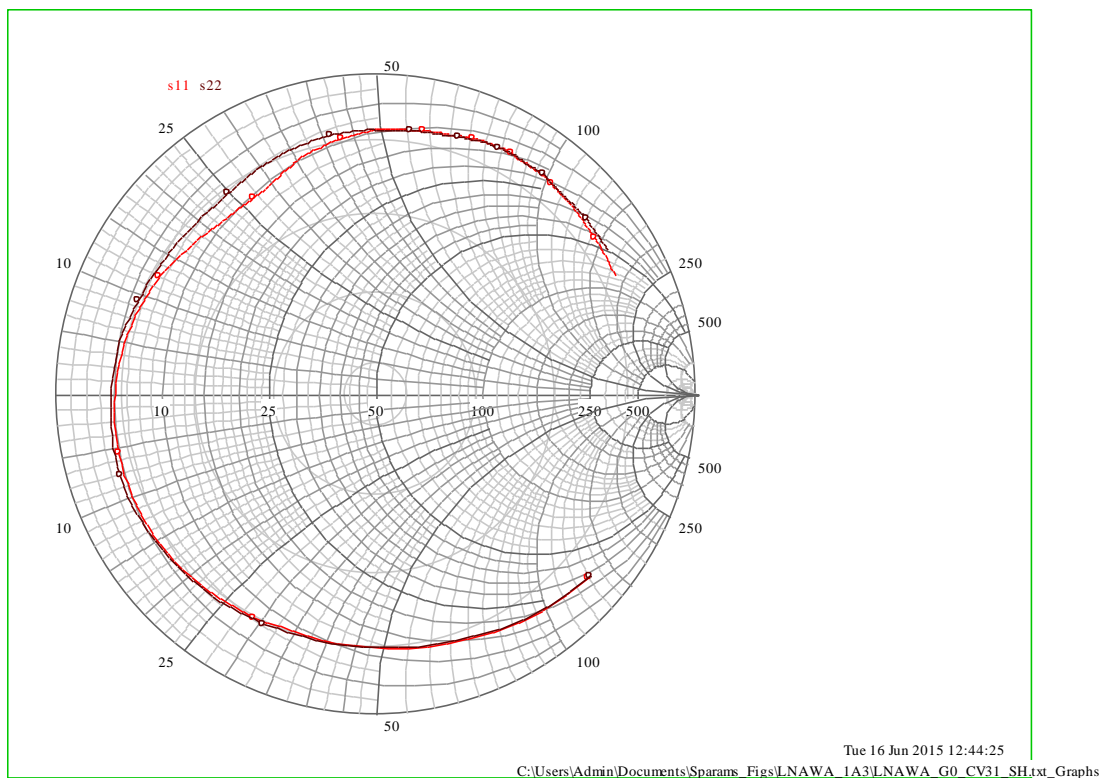
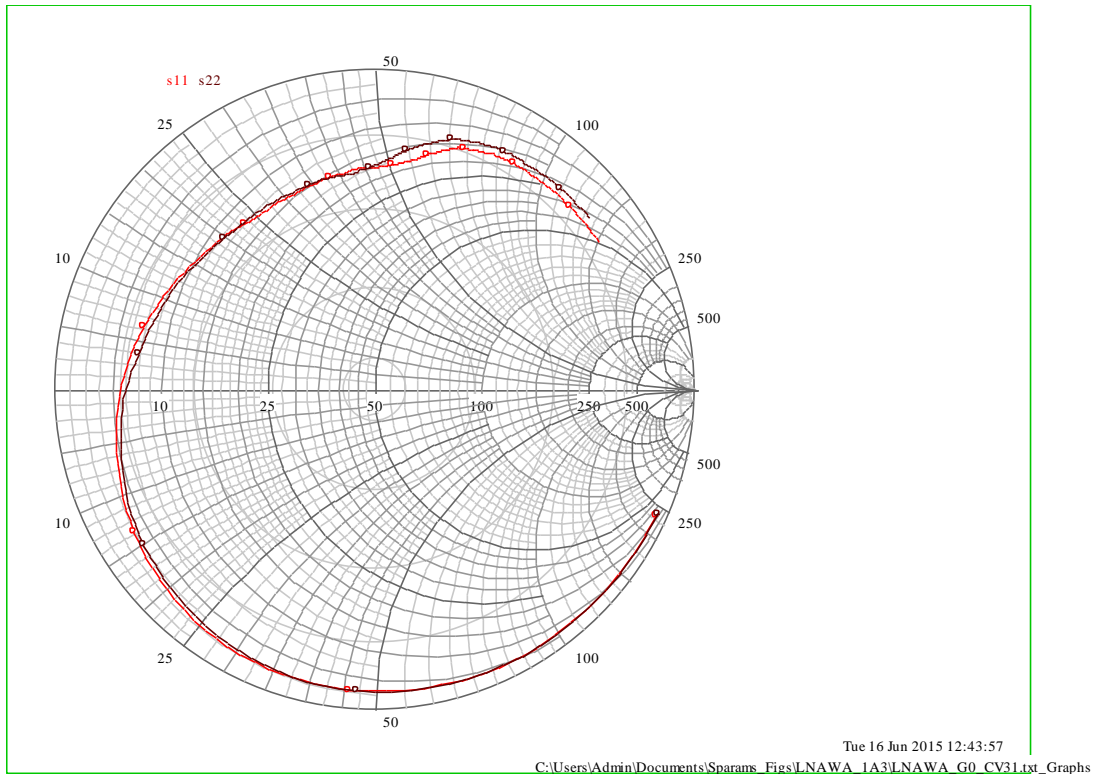


Figure 167 LNAWA Sample=3 Gain=0, Cap_Var =20 Short=1



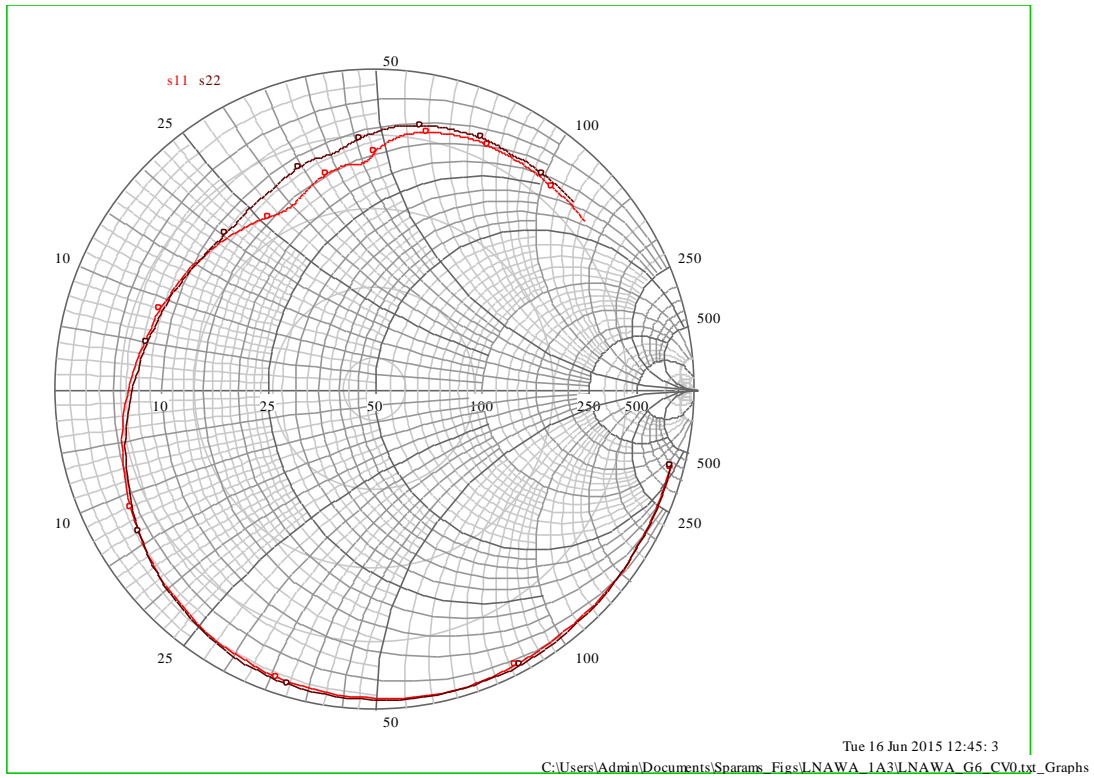


Figure 170 LNWA Sample=3 Gain=6, Cap_Var =0 Short=0

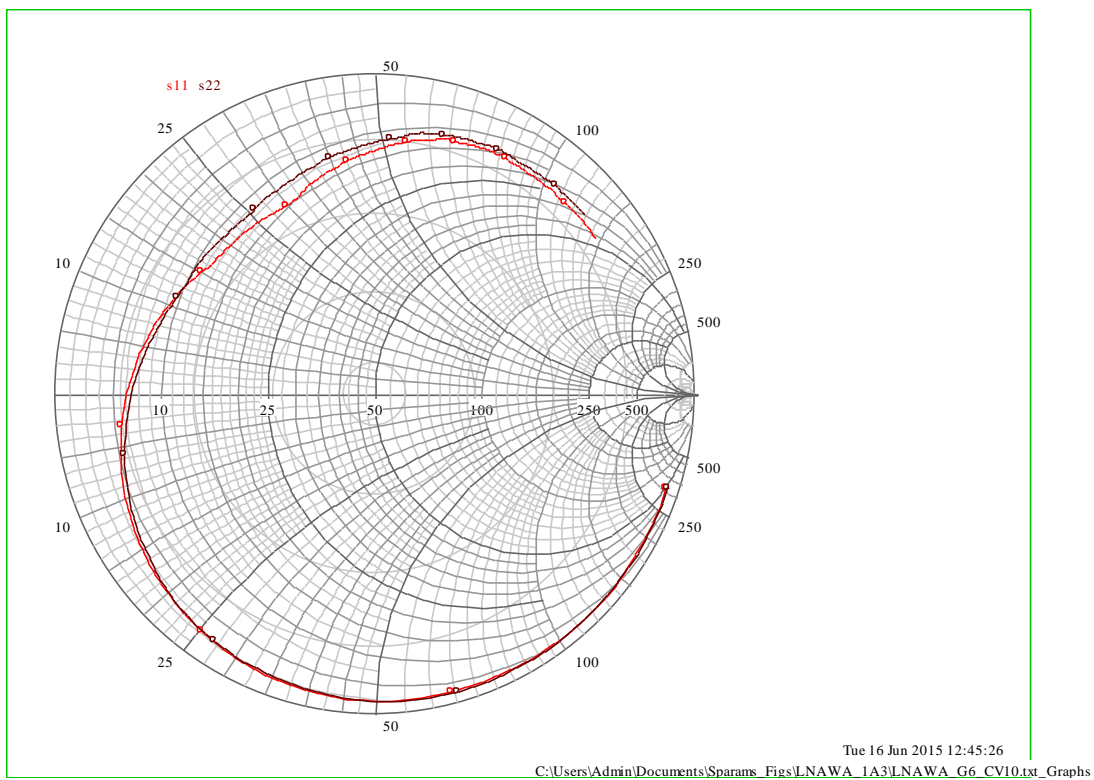


Figure 171 LNWA Sample=3 Gain=6, Cap_Var =10 Short=0

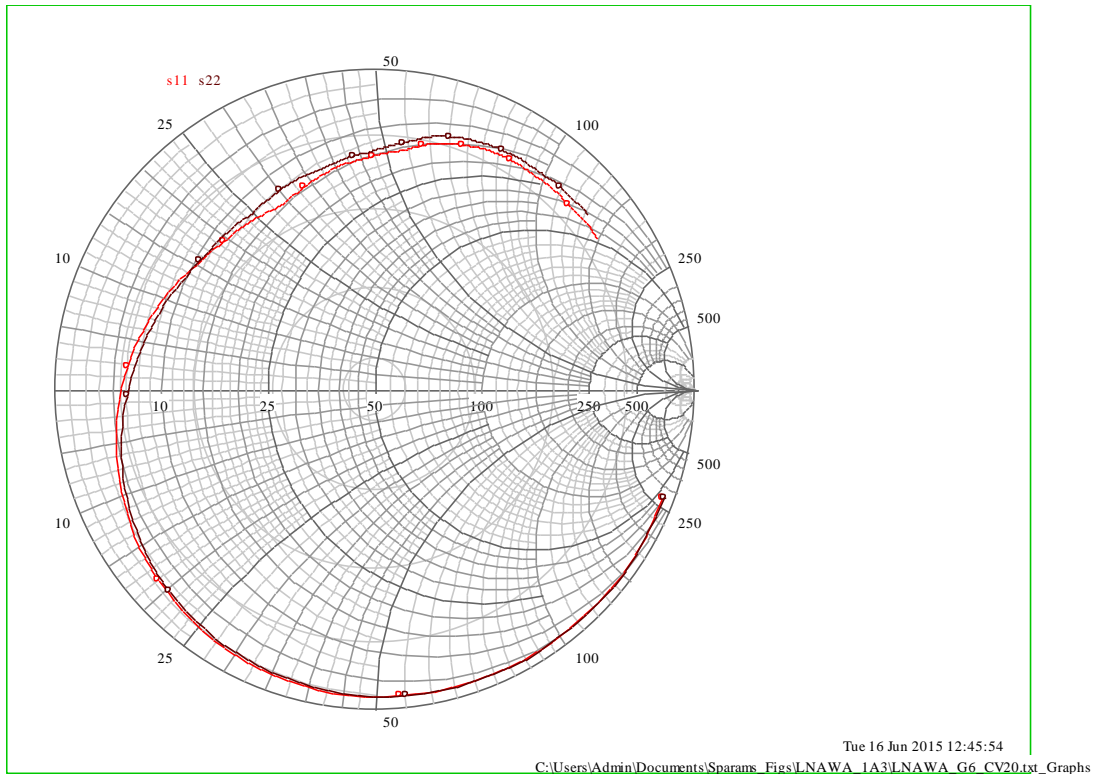


Figure 172 LNAWA Sample=3 Gain=6, Cap_Var =20 Short=0

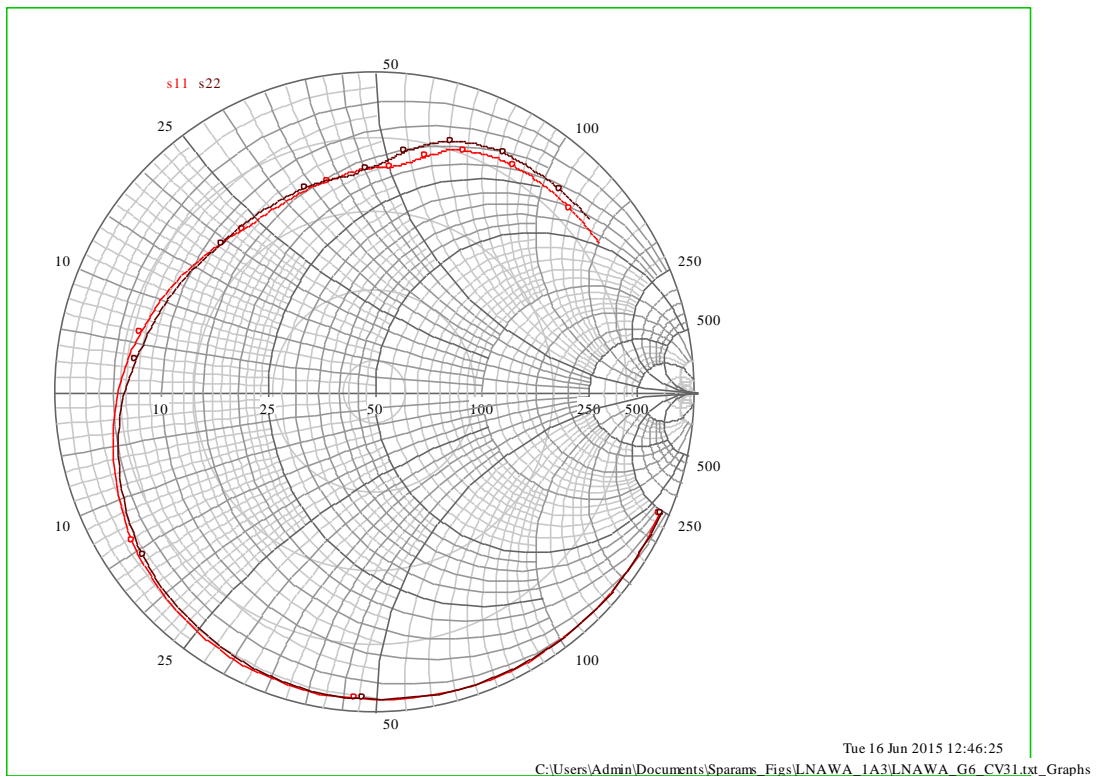


Figure 173 LNAWA Sample=3 Gain=6, Cap_Var =31 Short=0

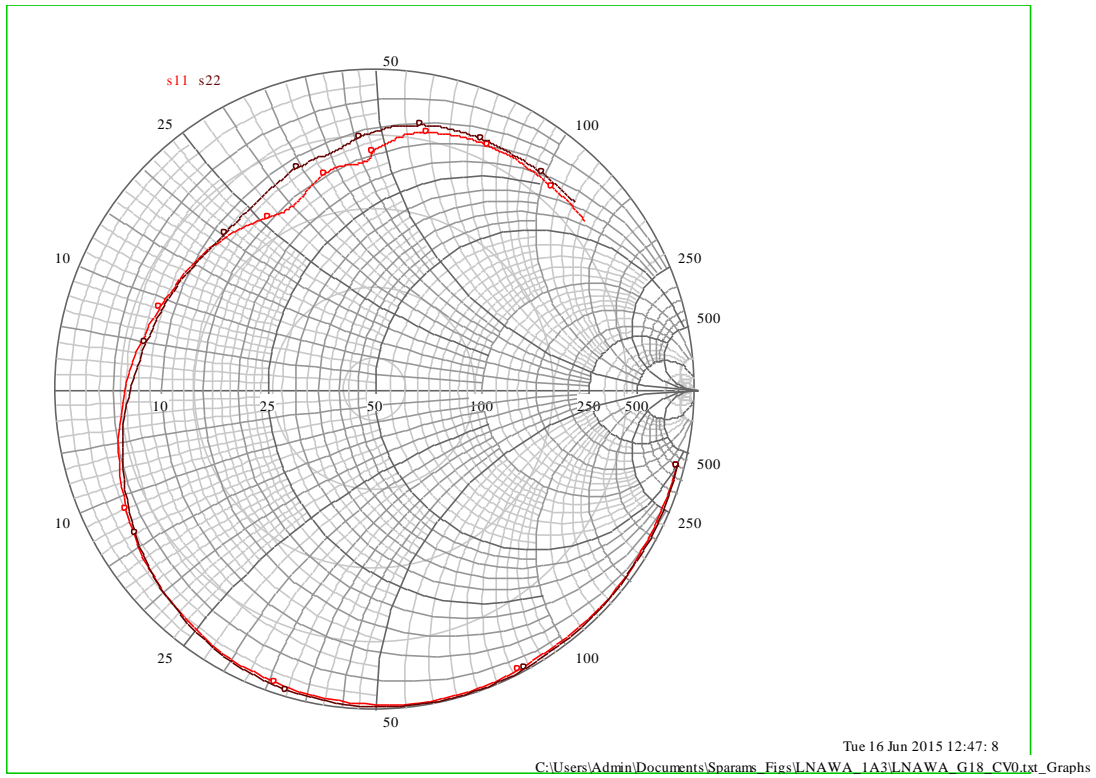


Figure 174 LNAWA Sample=3 Gain=18, Cap_Var =0 Short=0

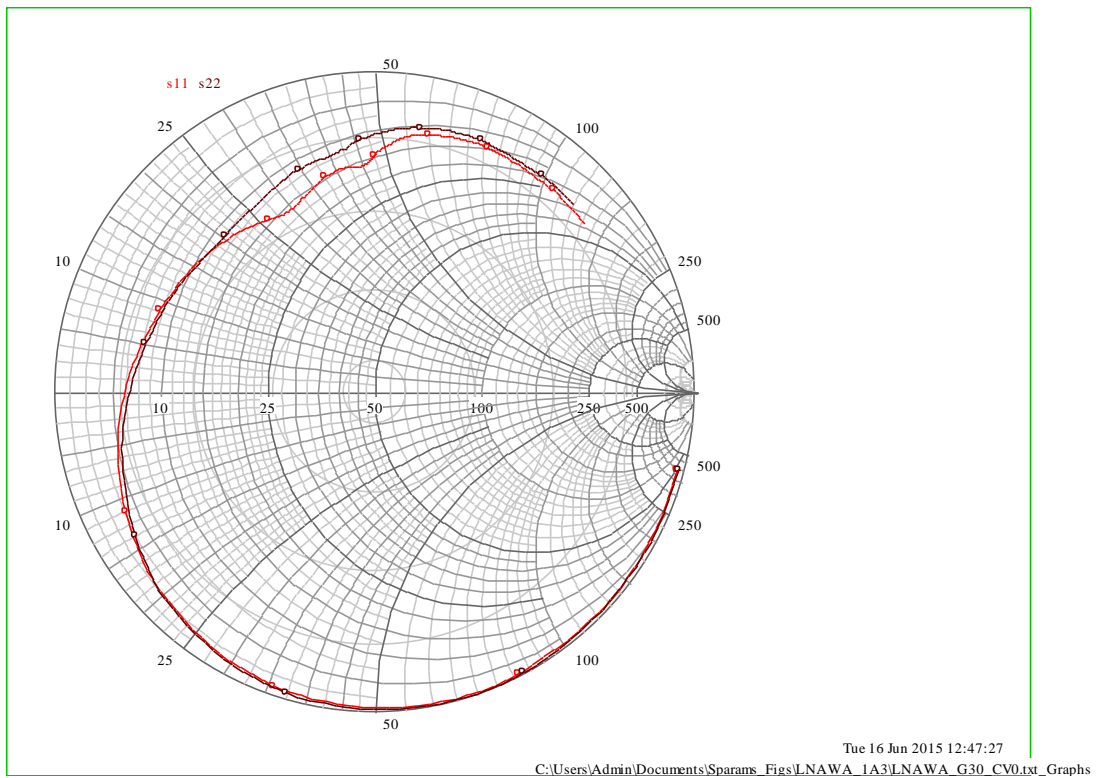


Figure 175 LNAWA Sample=3 Gain=31, Cap_Var =0 Short=0

4.15 LNAW Channel B Sample 1

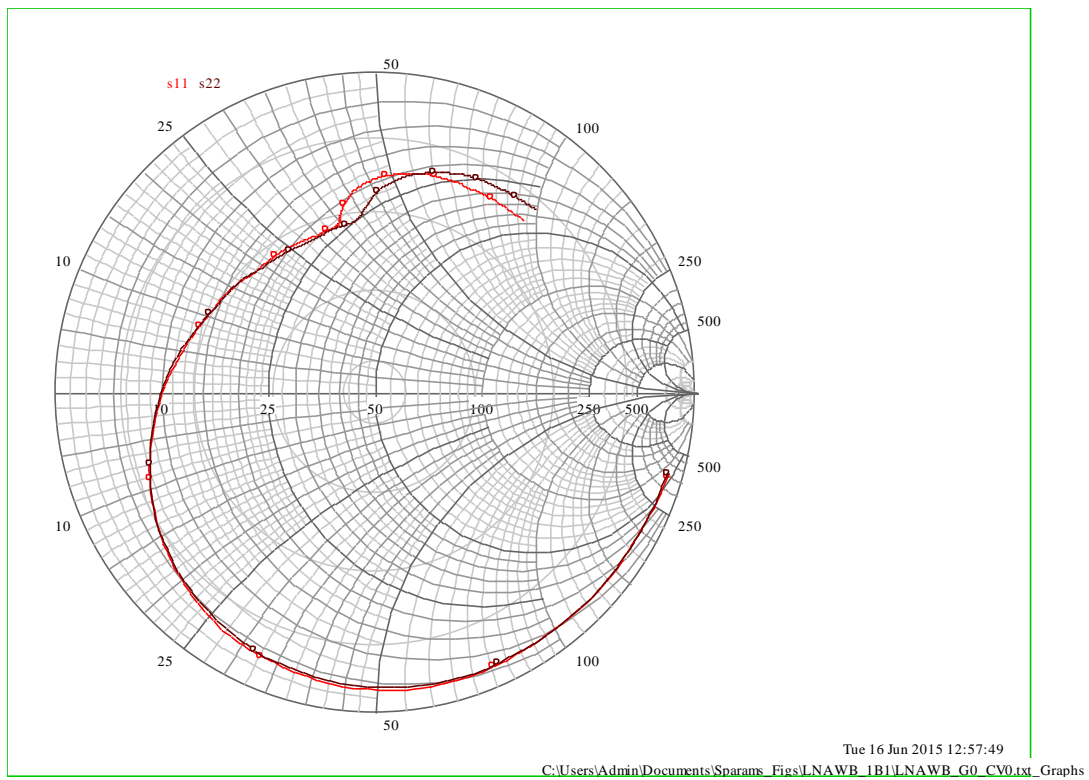


Figure 176 LNAWB Sample=1 Gain=0, Cap_Var=0 Short=0

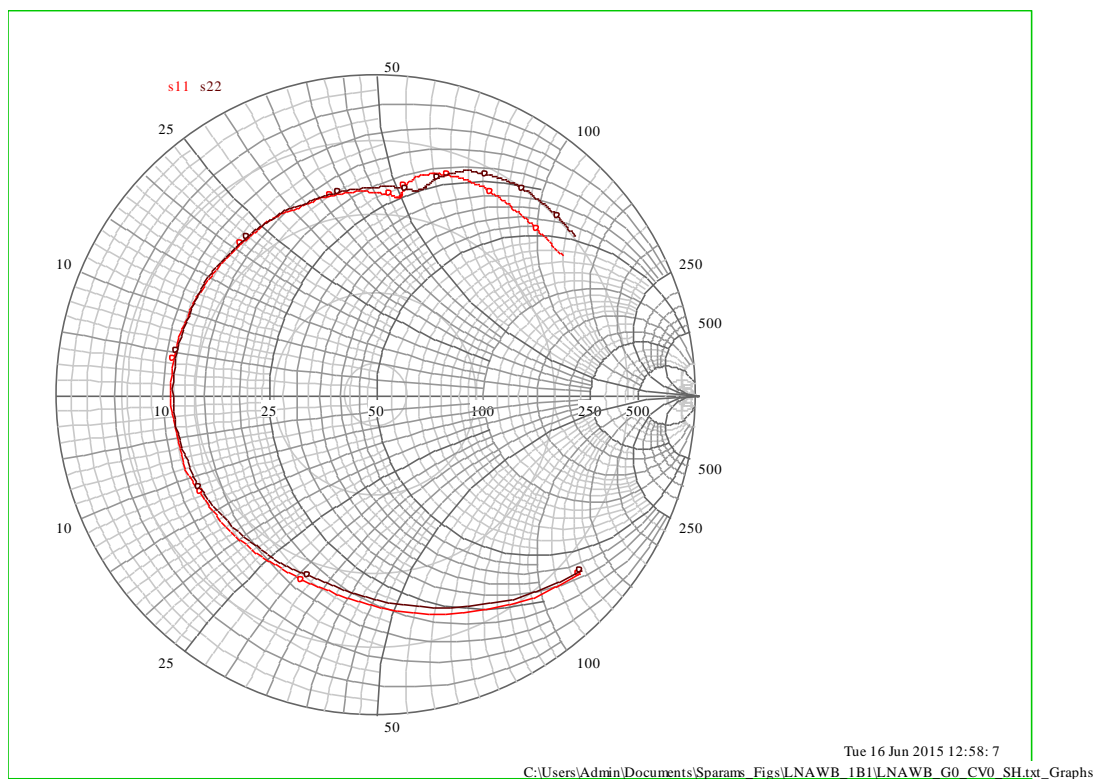


Figure 177 LNAWB Sample=1 Gain=0, Cap_Var=0 Short=1

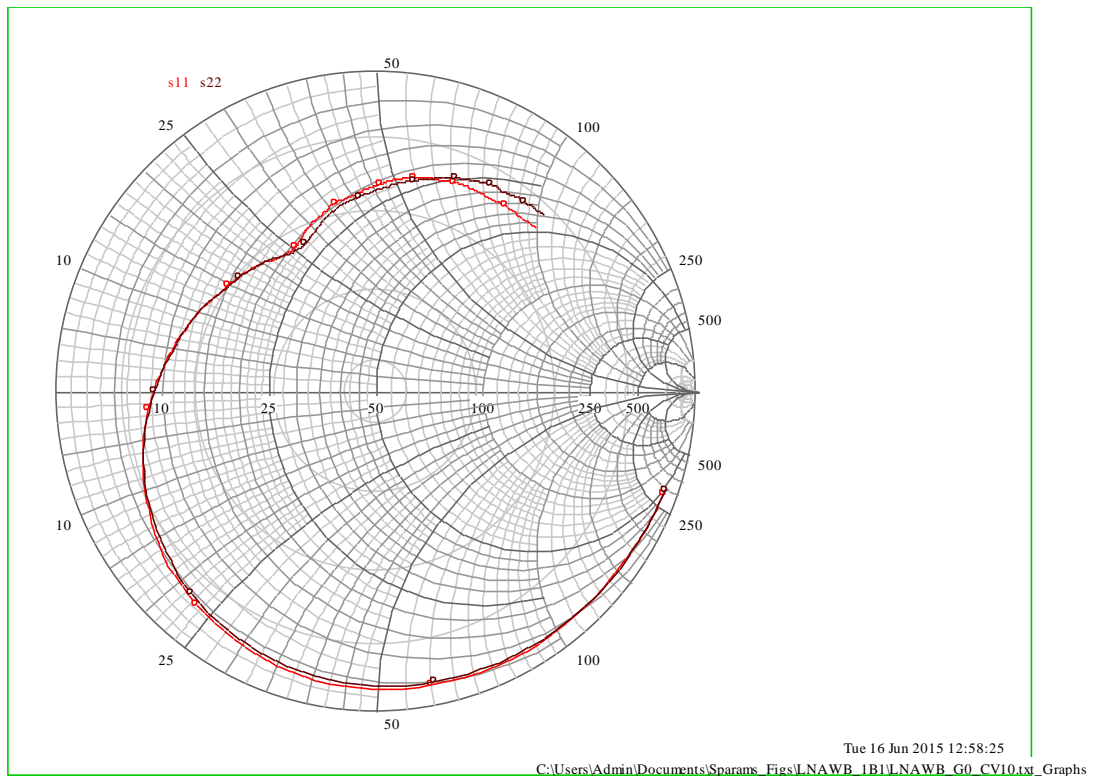


Figure 178 LNAWB Sample=1 Gain=0, Cap_Var =10 Short=0

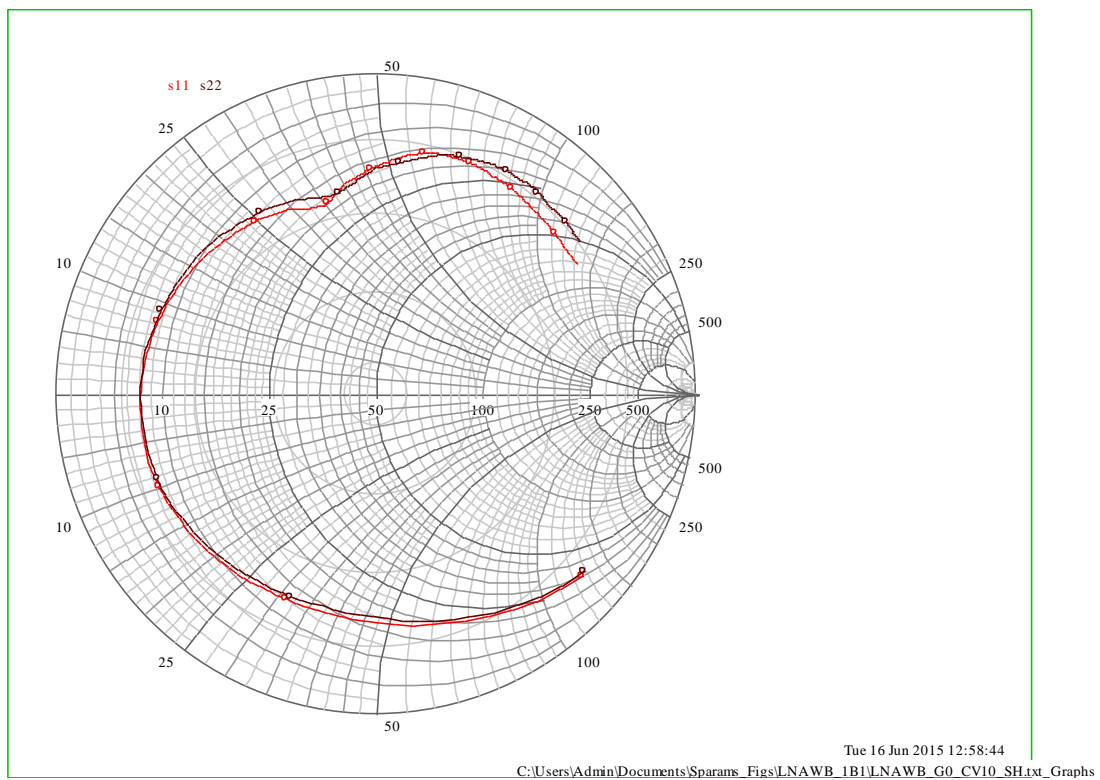


Figure 179 LNAWB Sample=1 Gain=0, Cap_Var =10 Short=1

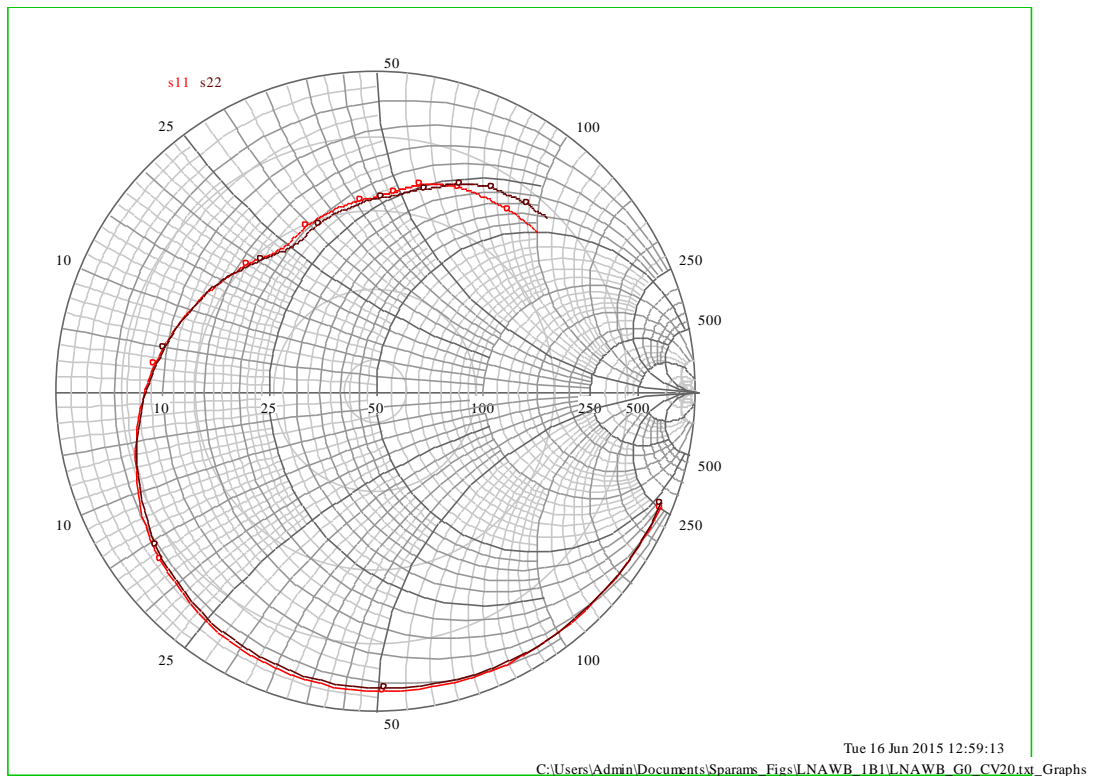


Figure 180 LNAWB Sample=1 Gain=0, Cap_Var =20 Short=0

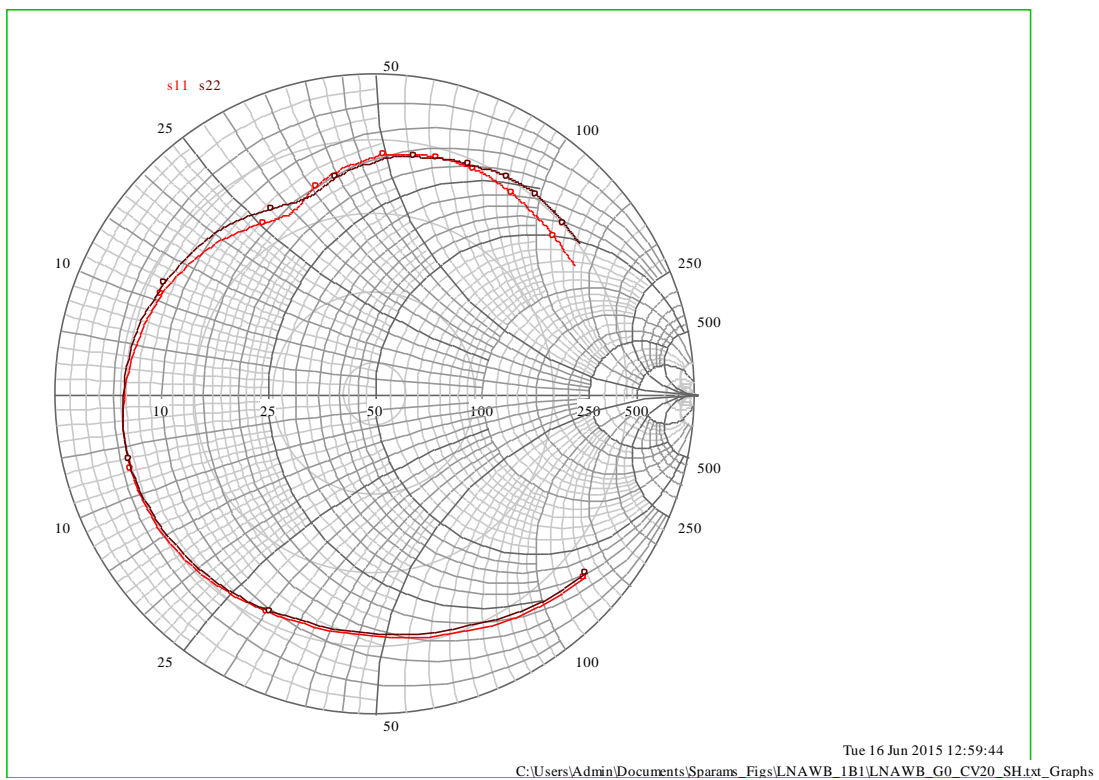


Figure 181 LNAWB Sample=1 Gain=0, Cap_Var =20 Short=1

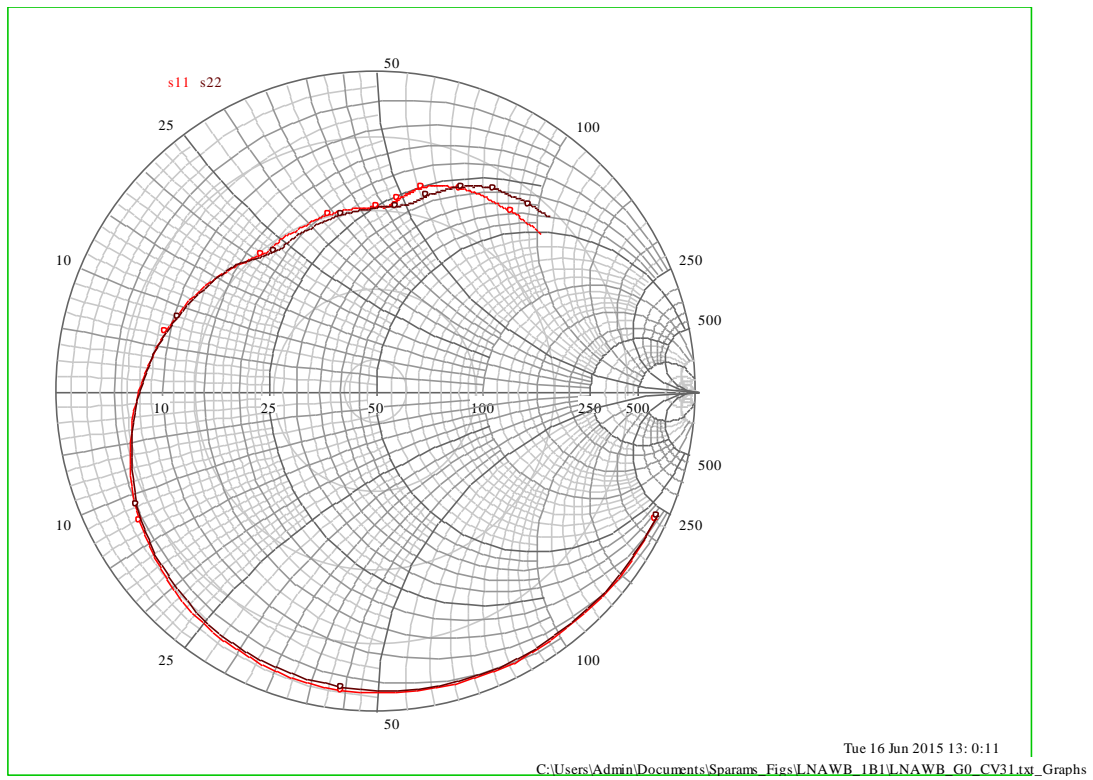


Figure 182 LNAWB Sample=1 Gain=0, Cap_Var =31 Short=0

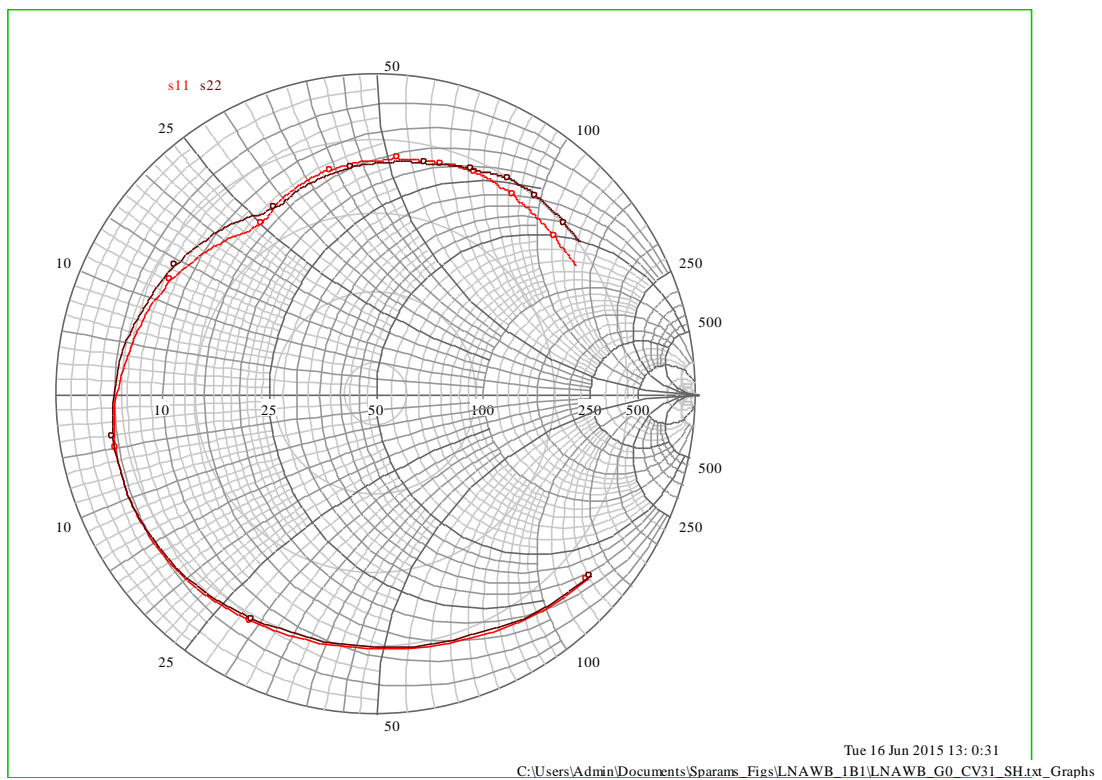


Figure 183 LNAWB Sample=1 Gain=0, Cap_Var =31 Short=1

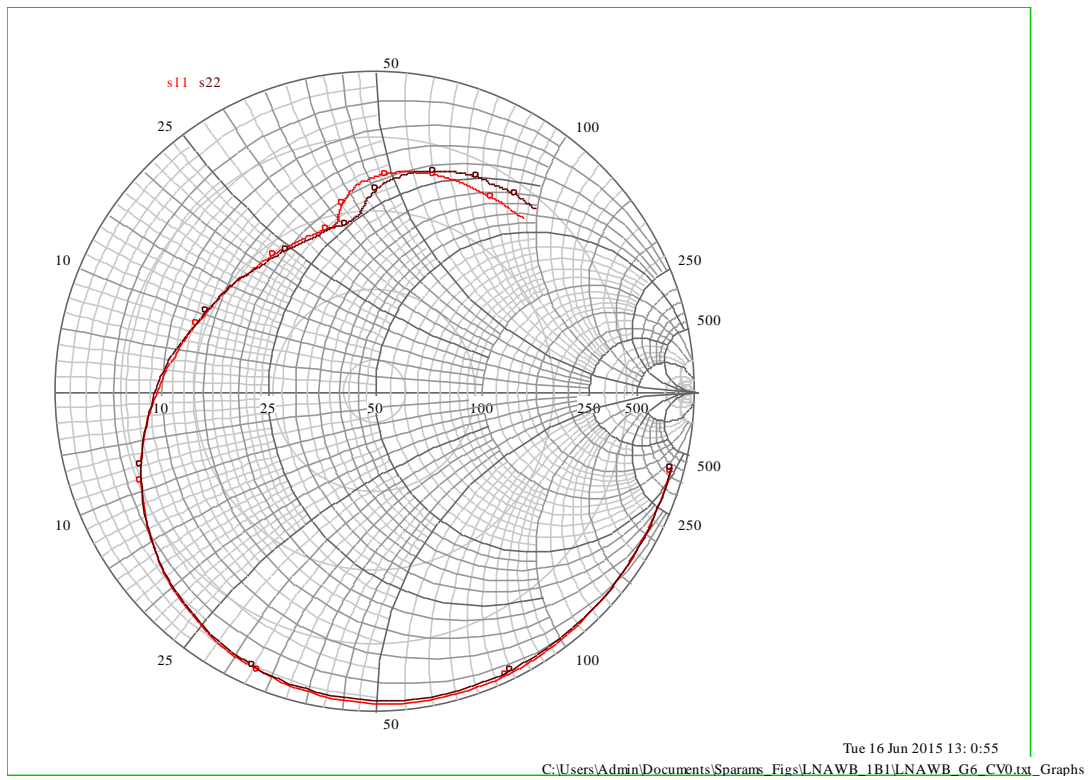


Figure 184 LNAWB Sample=1 Gain=6, Cap_Var =0 Short=0

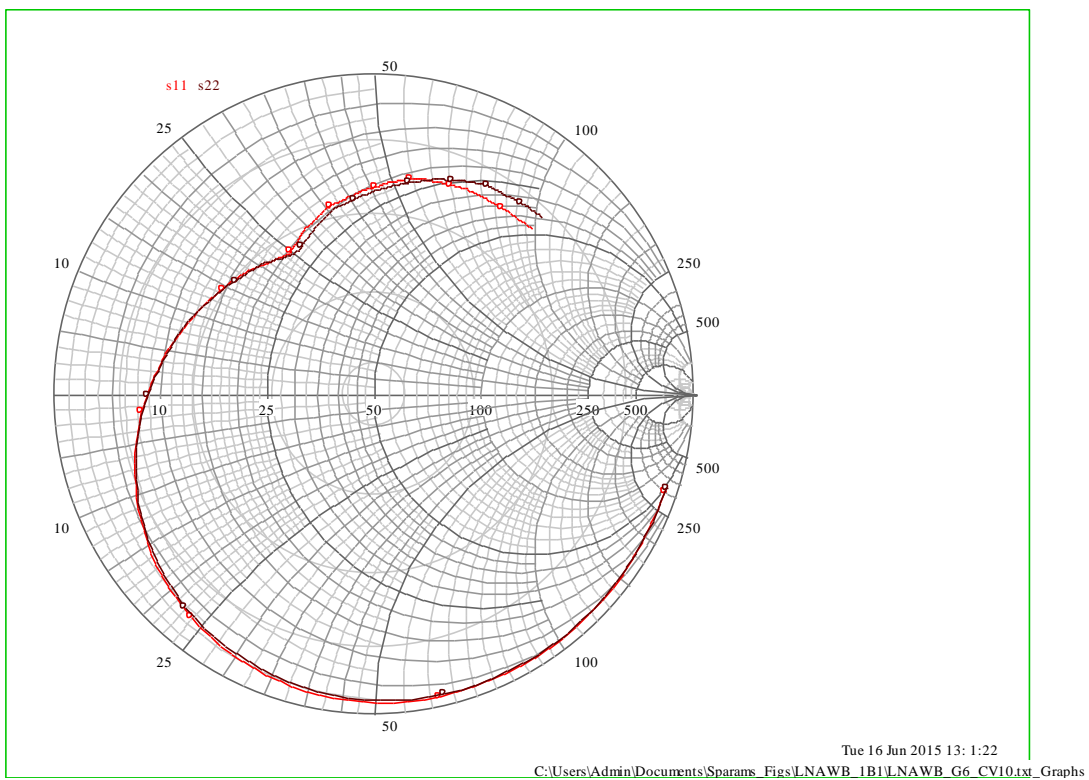


Figure 185 LNAWB Sample=1 Gain=6, Cap_Var =10 Short=0

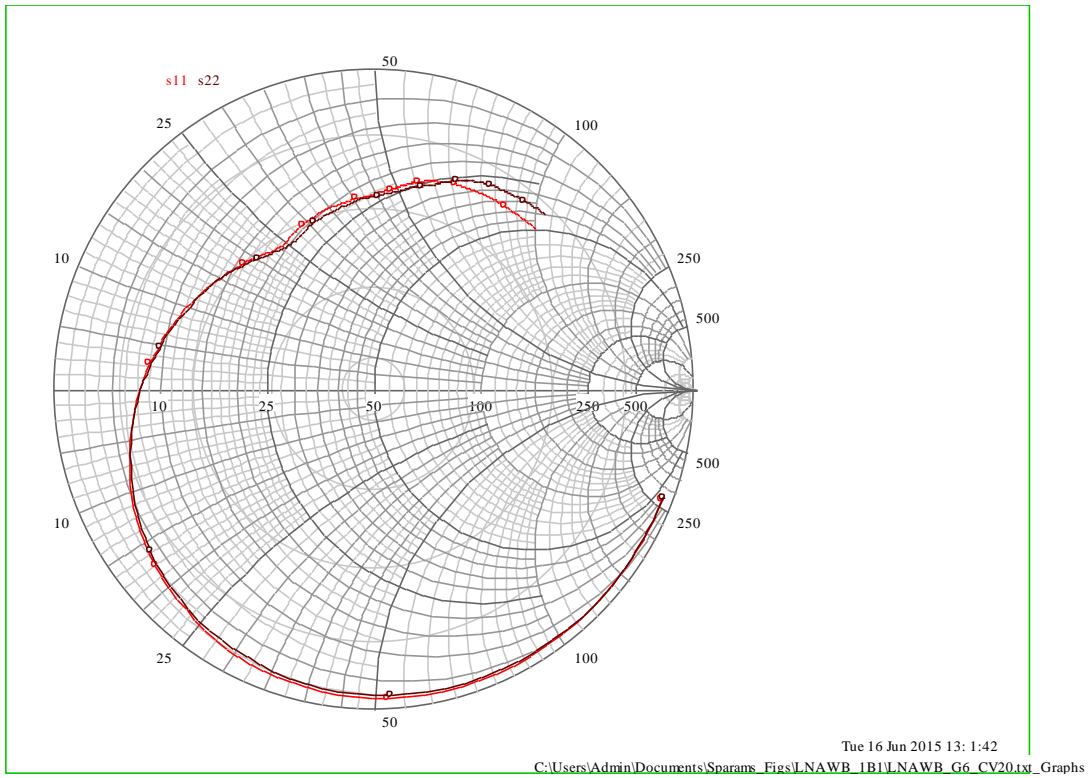


Figure 186 LNAWB Sample=1 Gain=6, Cap_Var =20 Short=0

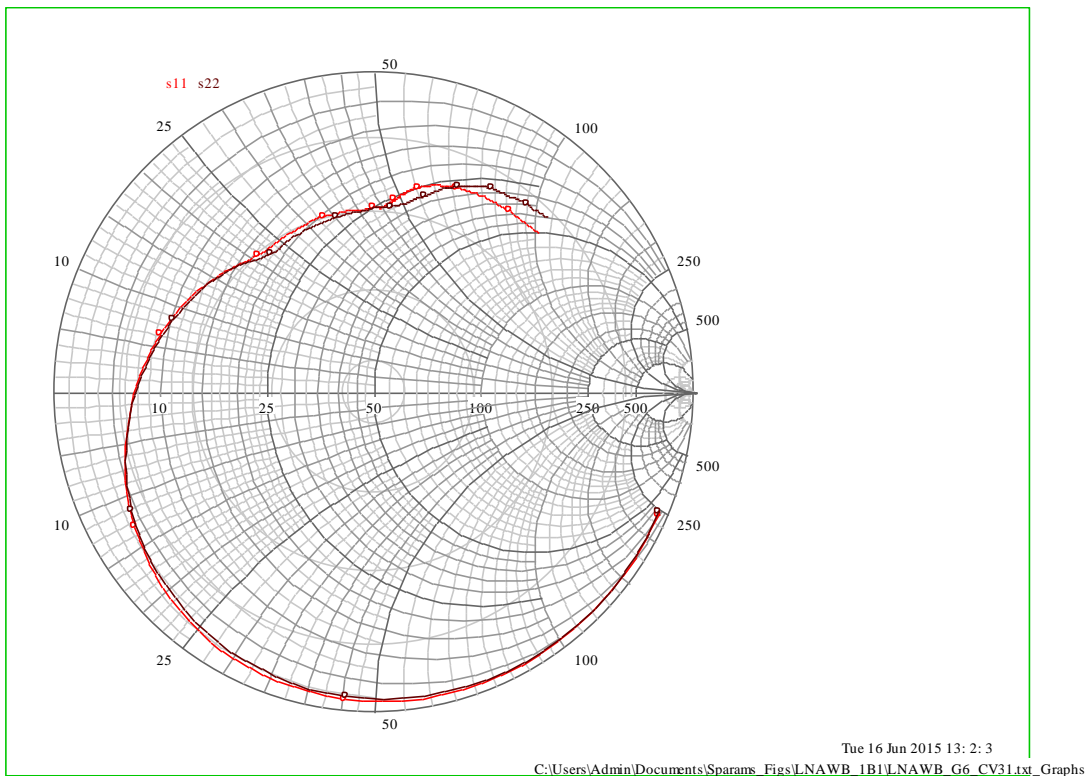


Figure 187 LNAWB Sample=1 Gain=6, Cap_Var =31 Short=0

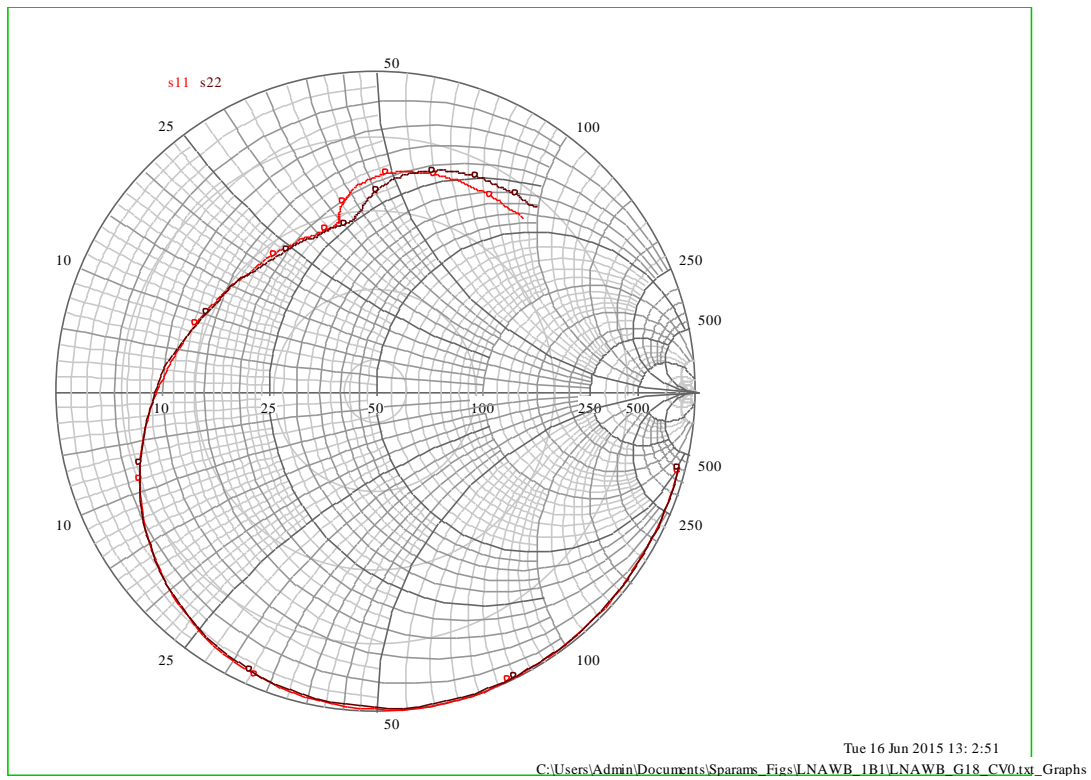


Figure 188 LNAWB Sample=1 Gain=18, Cap_Var =0 Short=0

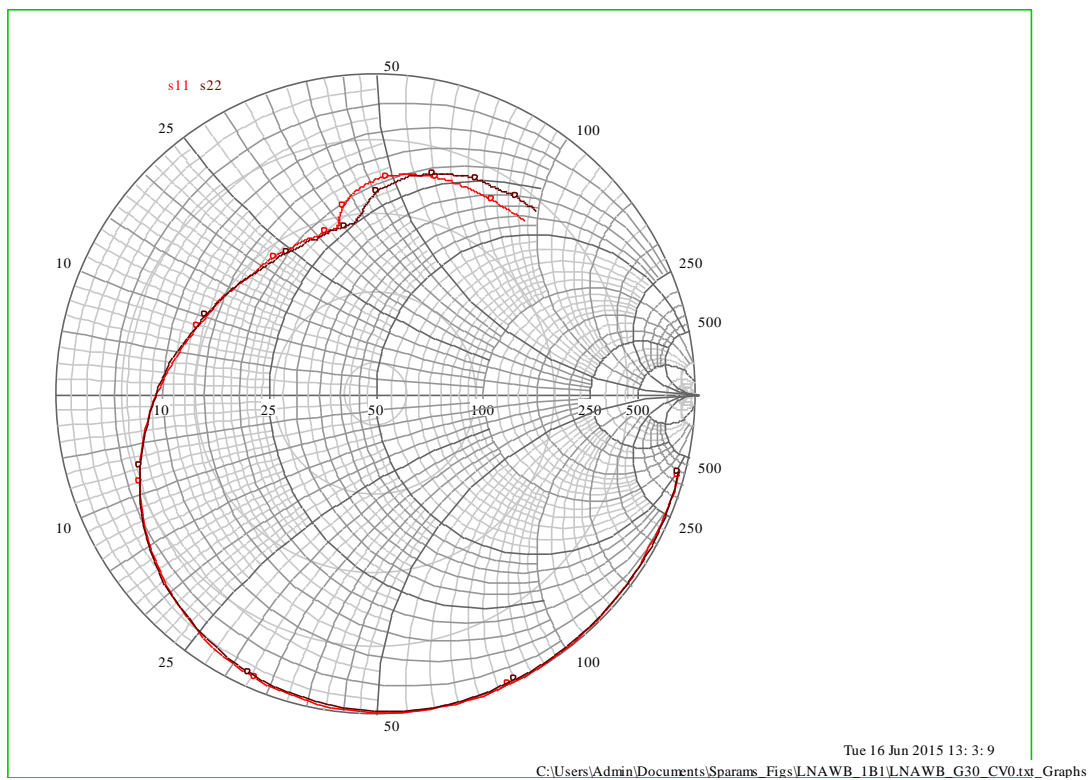


Figure 189 LNAWB Sample=1 Gain=31, Cap_Var =0 Short=0

4.16 LNAW Channel B Sample 2

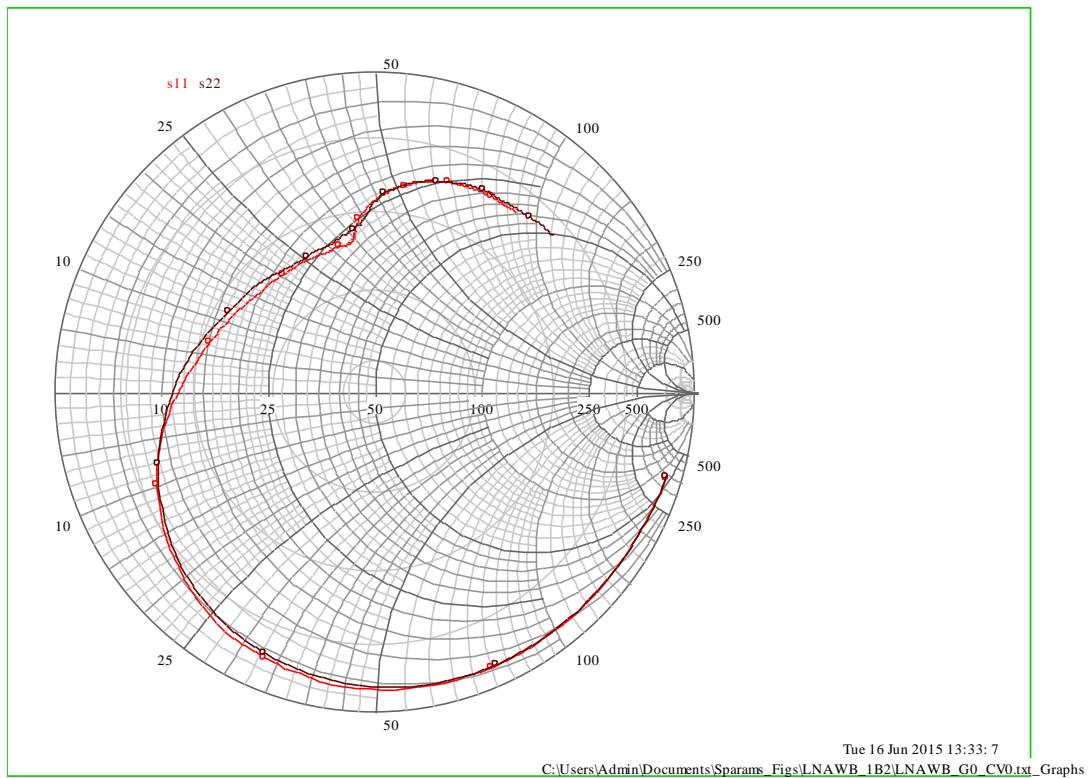


Figure 190 LNAWB Sample=2 Gain=0, Cap_Var=0 Short=0

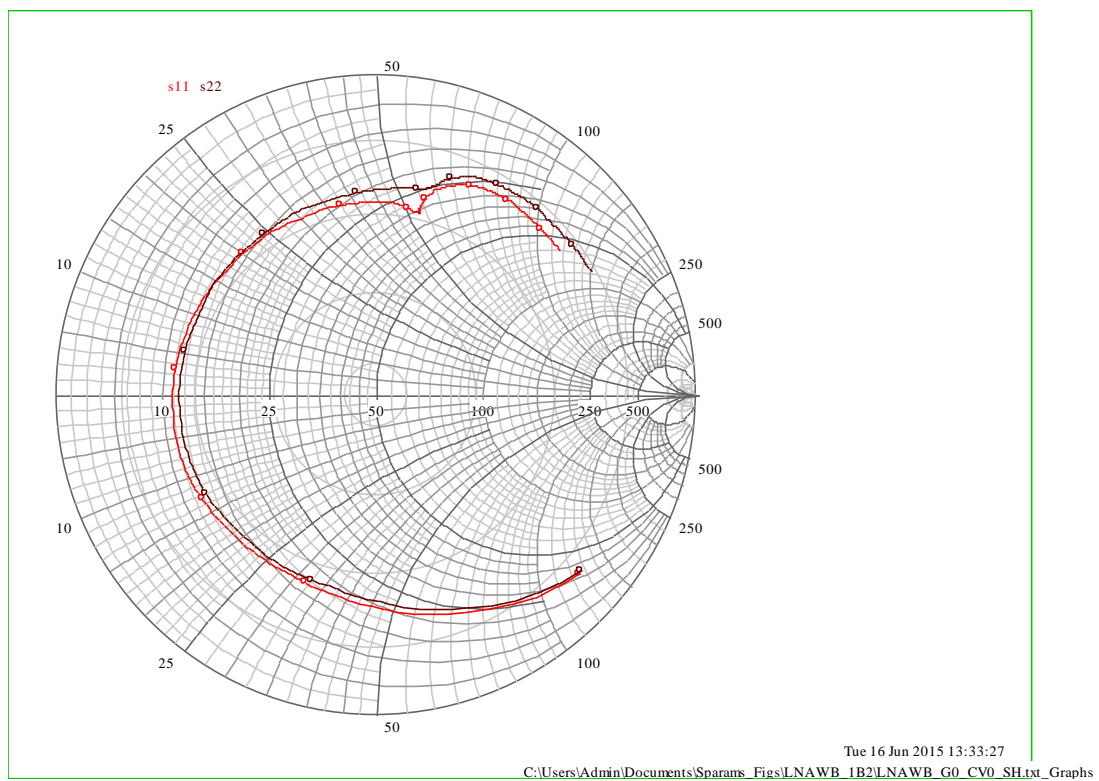


Figure 191 LNAWB Sample=2 Gain=0, Cap_Var=0 Short=1

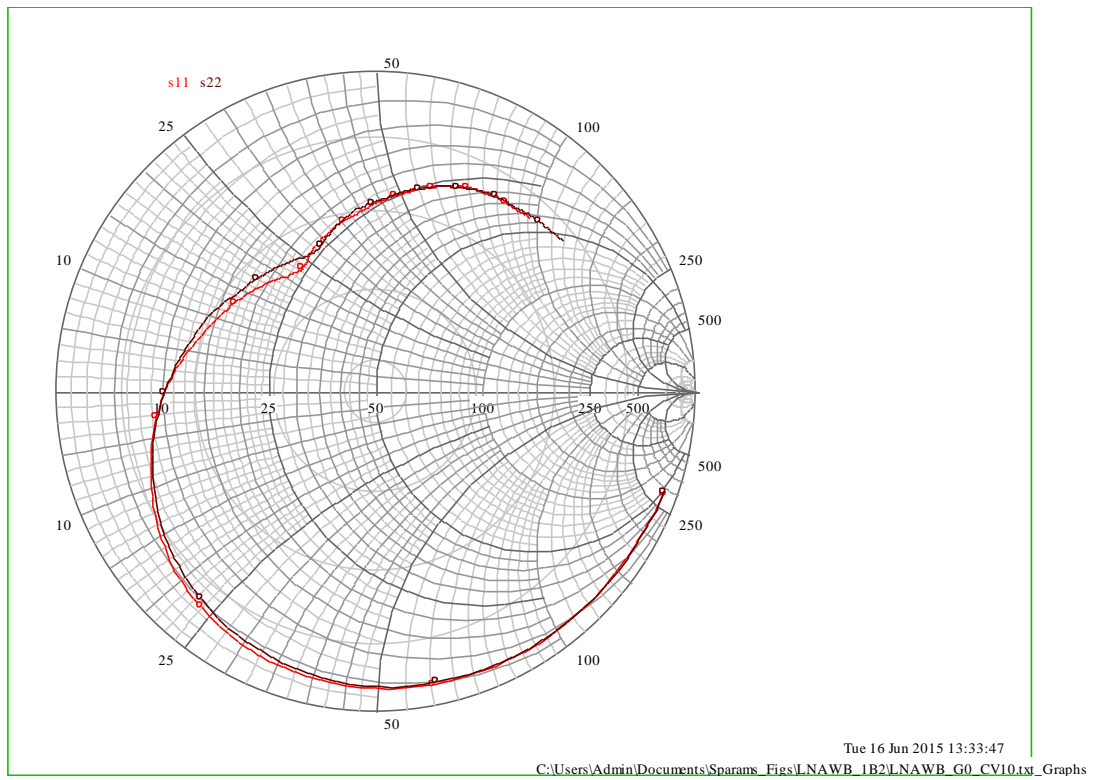


Figure 192 LNAWB Sample=2 Gain=0, Cap_Var =10 Short=0

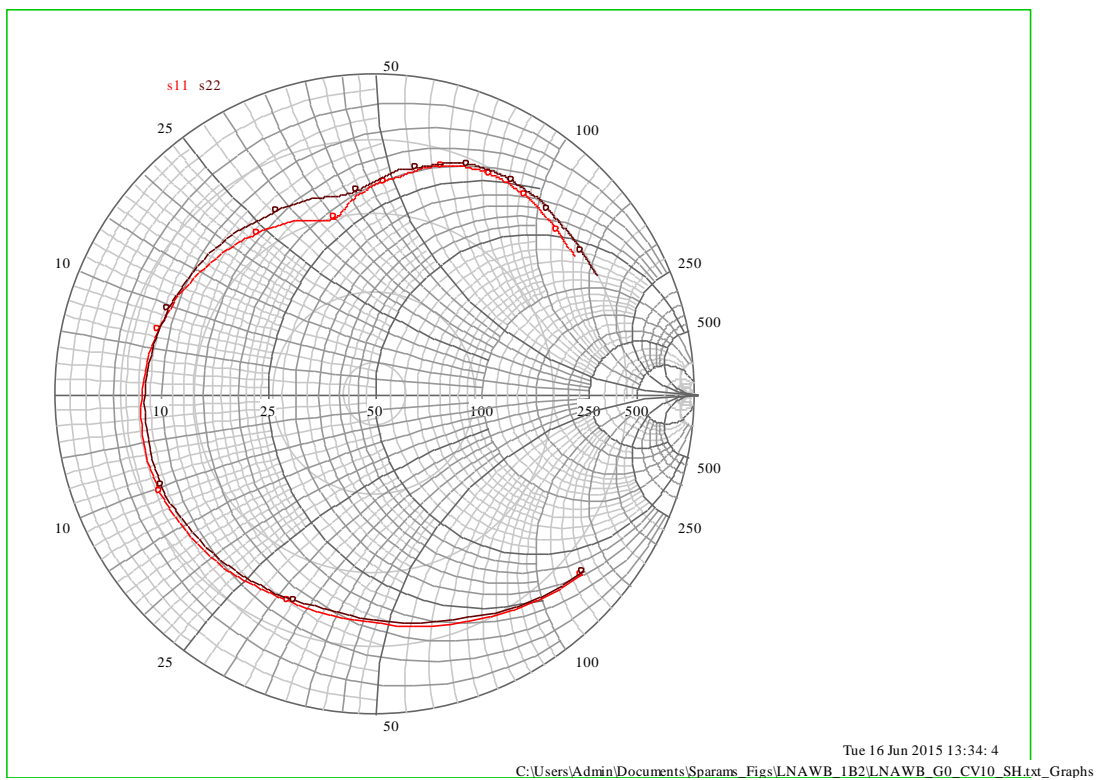


Figure 193 LNAWB Sample=2 Gain=0, Cap_Var =10 Short=1

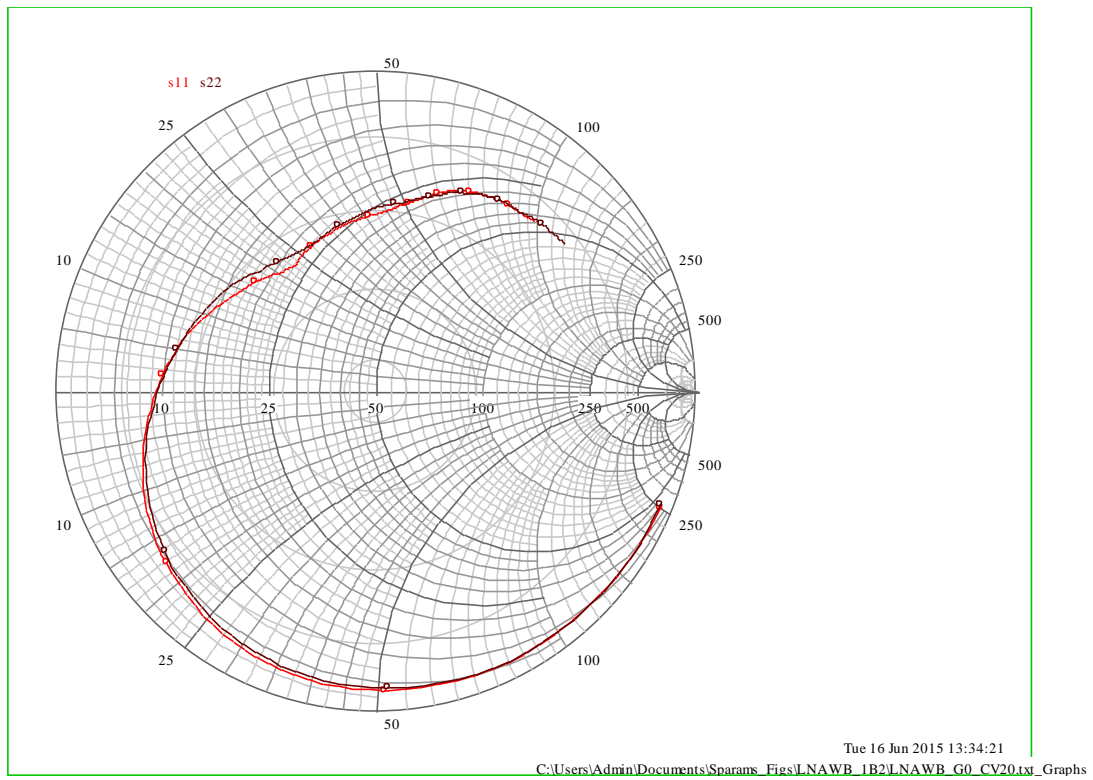


Figure 194 LNAWB Sample=2 Gain=0, Cap_Var =20 Short=0

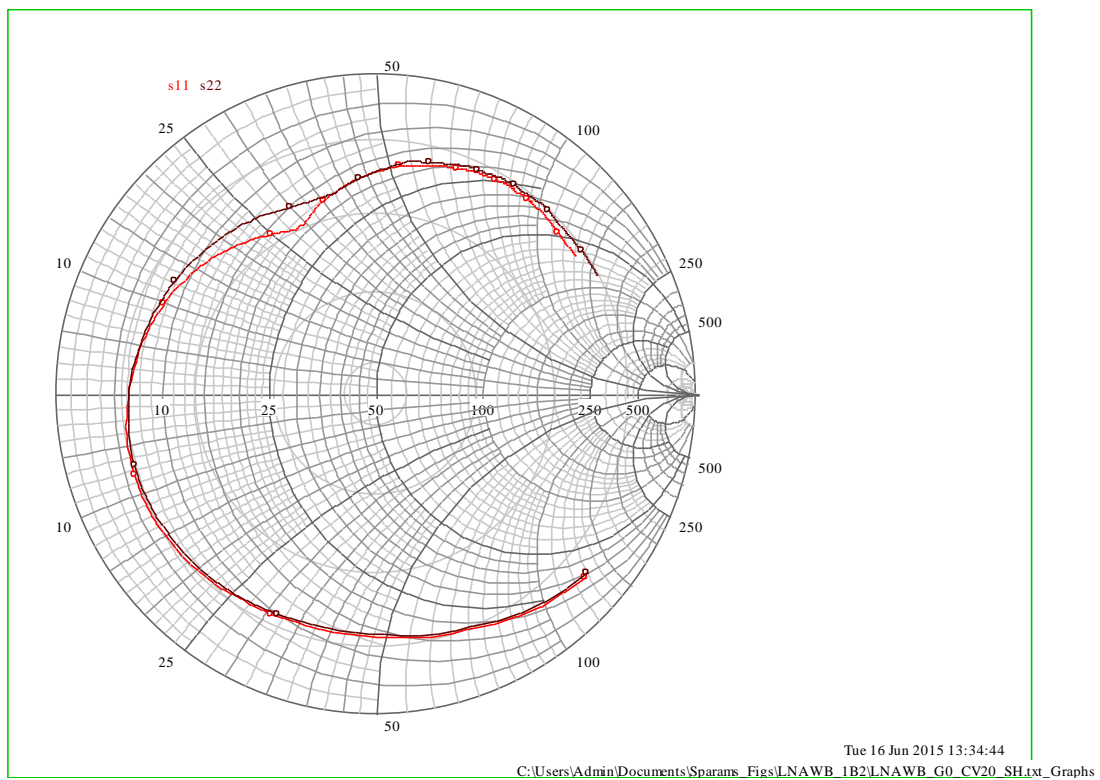


Figure 195 LNAWB Sample=2 Gain=0, Cap_Var =20 Short=1

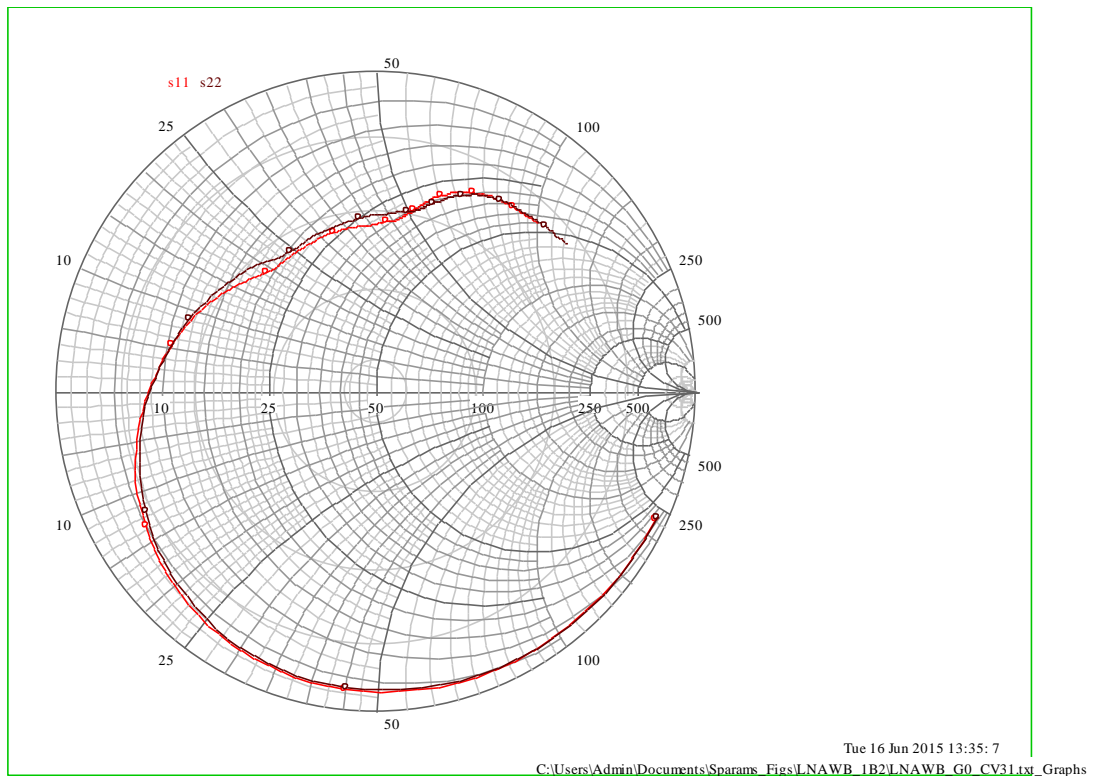


Figure 196 LNAWB Sample=2 Gain=0, Cap_Var =31 Short=0

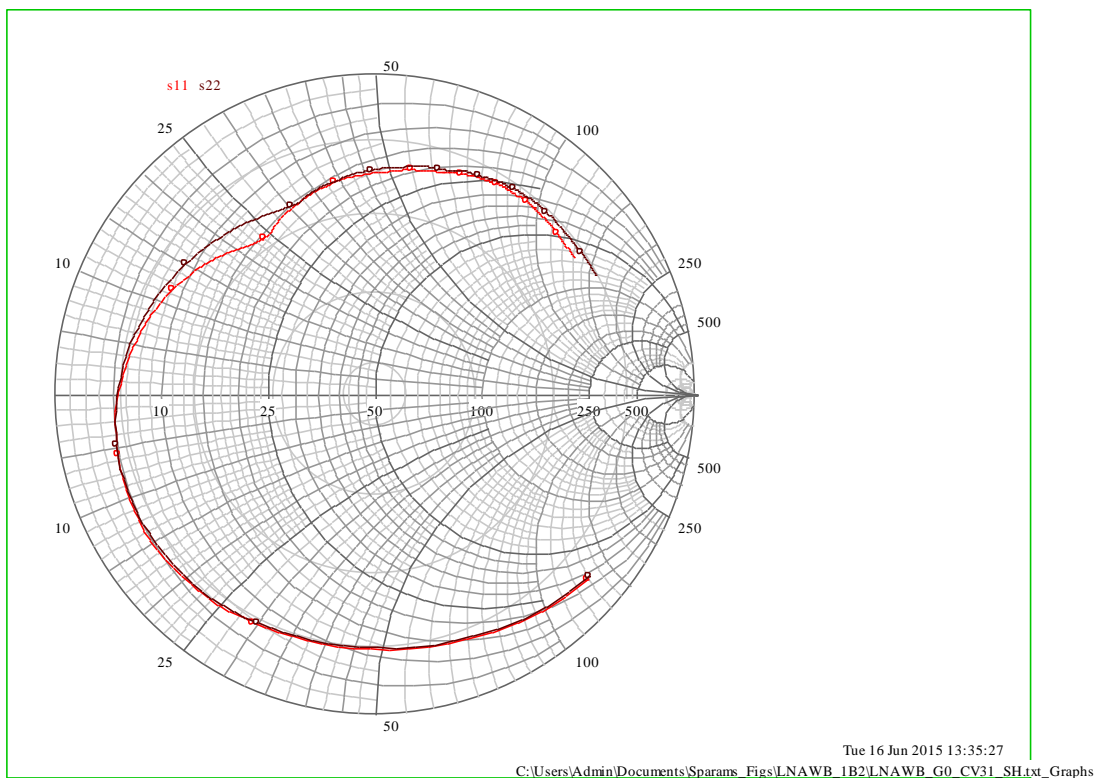


Figure 197 LNAWB Sample=2 Gain=0, Cap_Var =31 Short=1

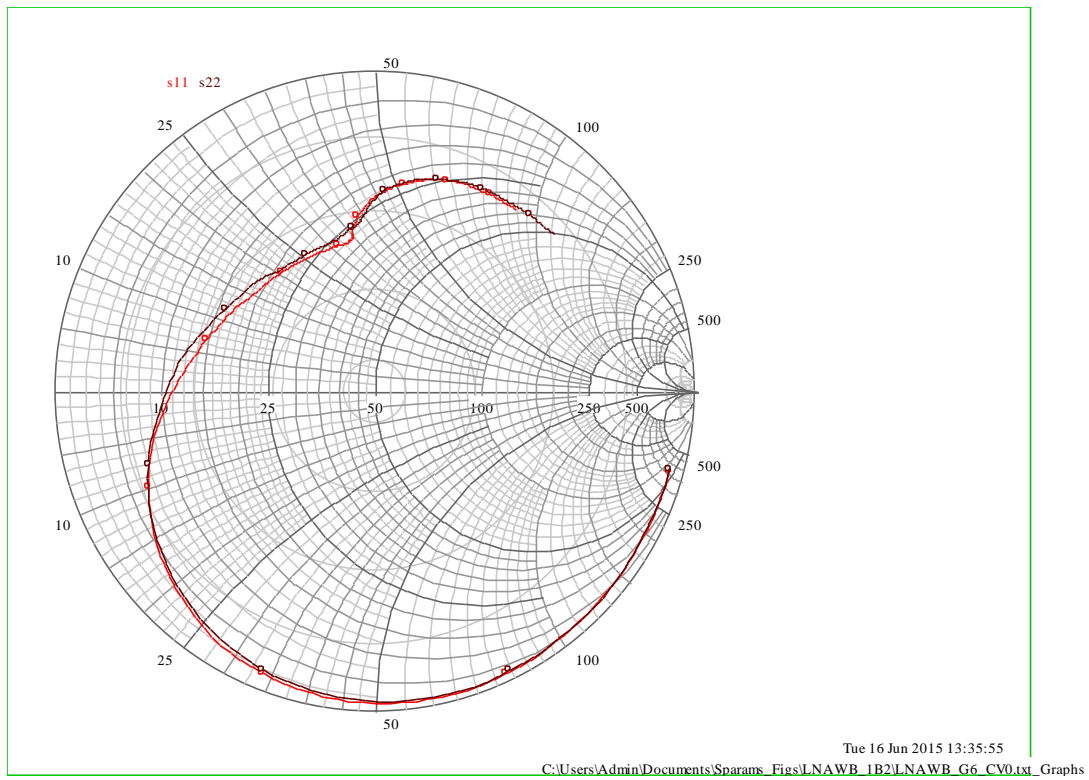


Figure 198 LNAWB Sample=2 Gain=6, Cap_Var =0 Short=0

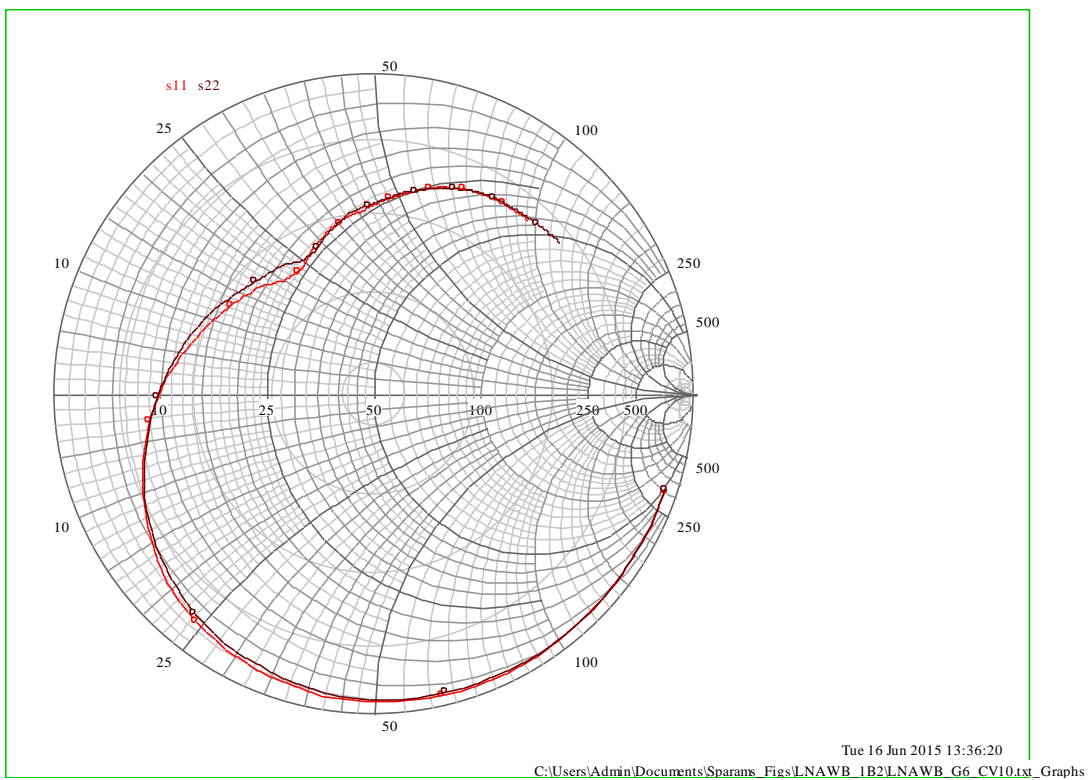


Figure 199 LNAWB Sample=2 Gain=6, Cap_Var =10 Short=0

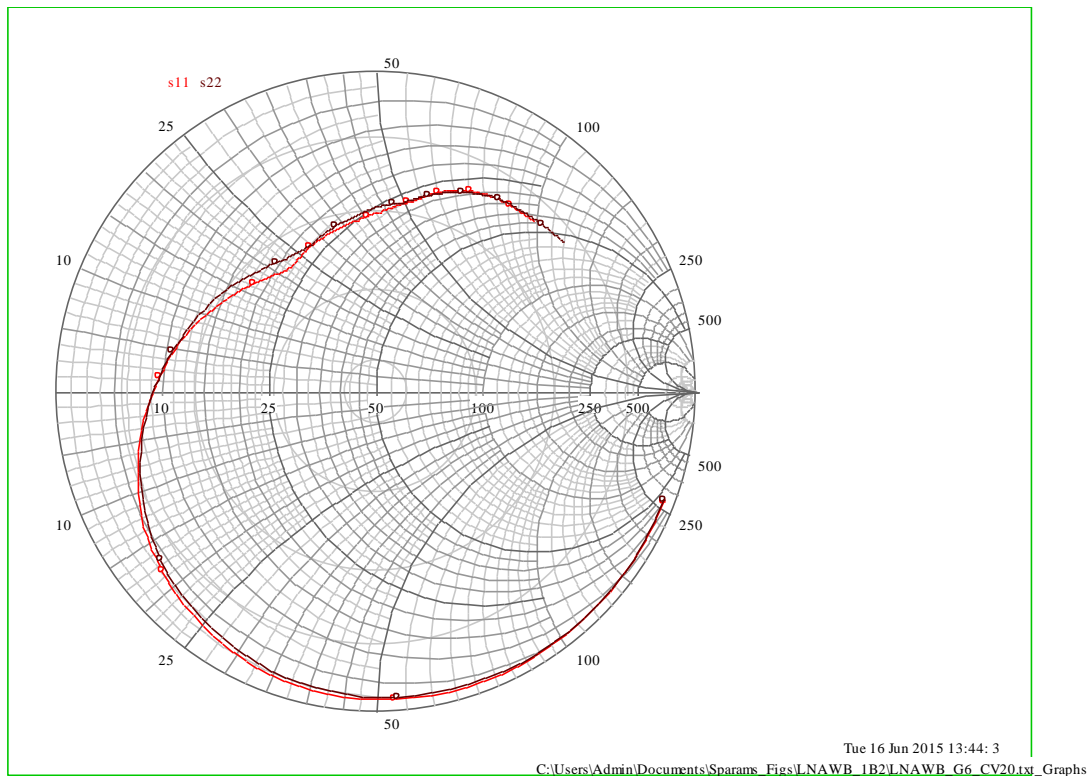


Figure 200 LNAWB Sample=2 Gain=6, Cap_Var =20 Short=0

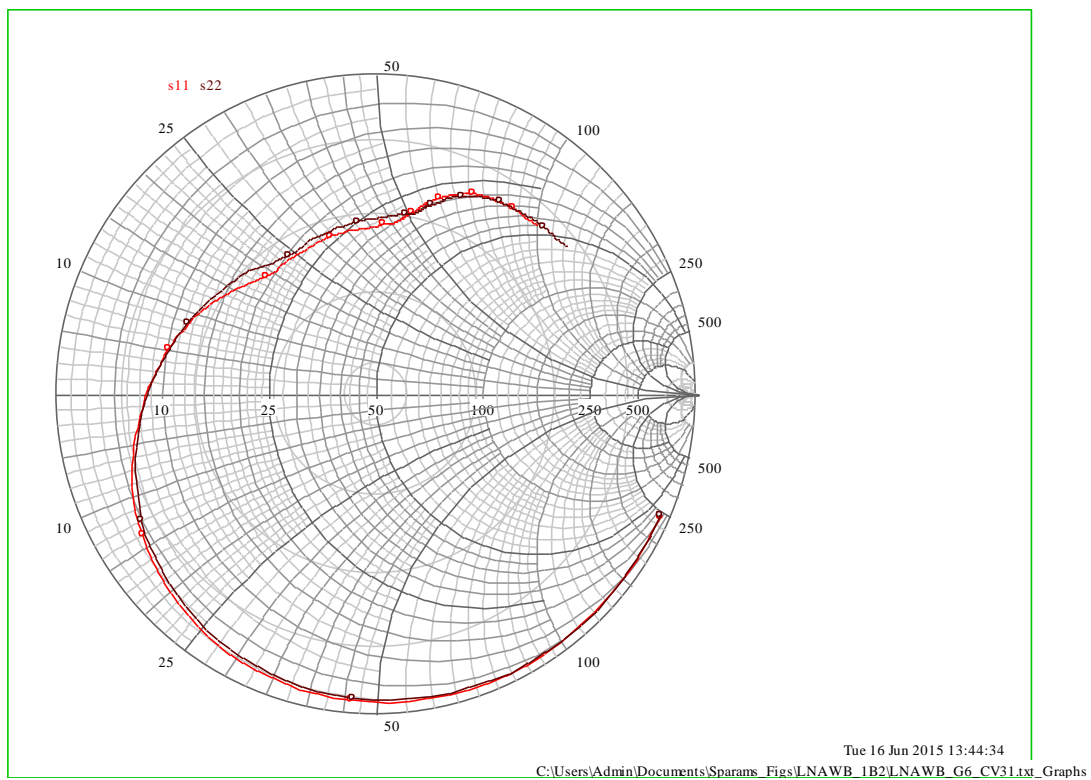


Figure 201 LNAWB Sample=2 Gain=6, Cap_Var =31 Short=0

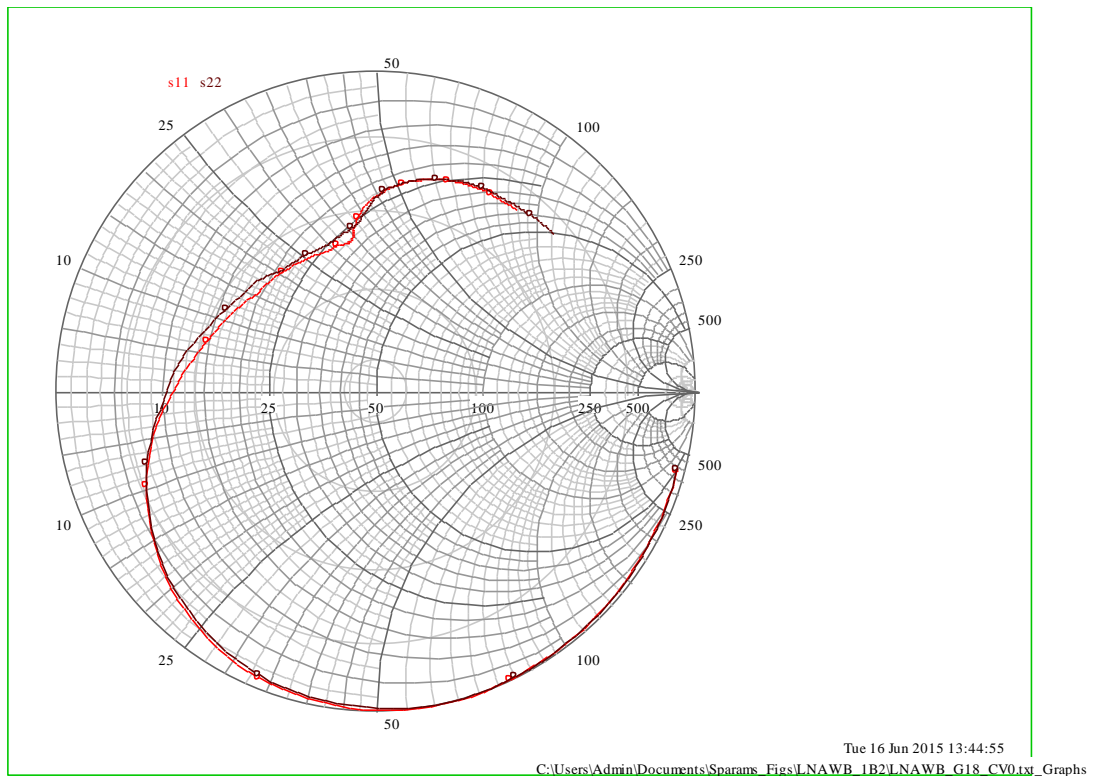


Figure 202 LNAWB Sample=2 Gain=18, Cap_Var =0 Short=0

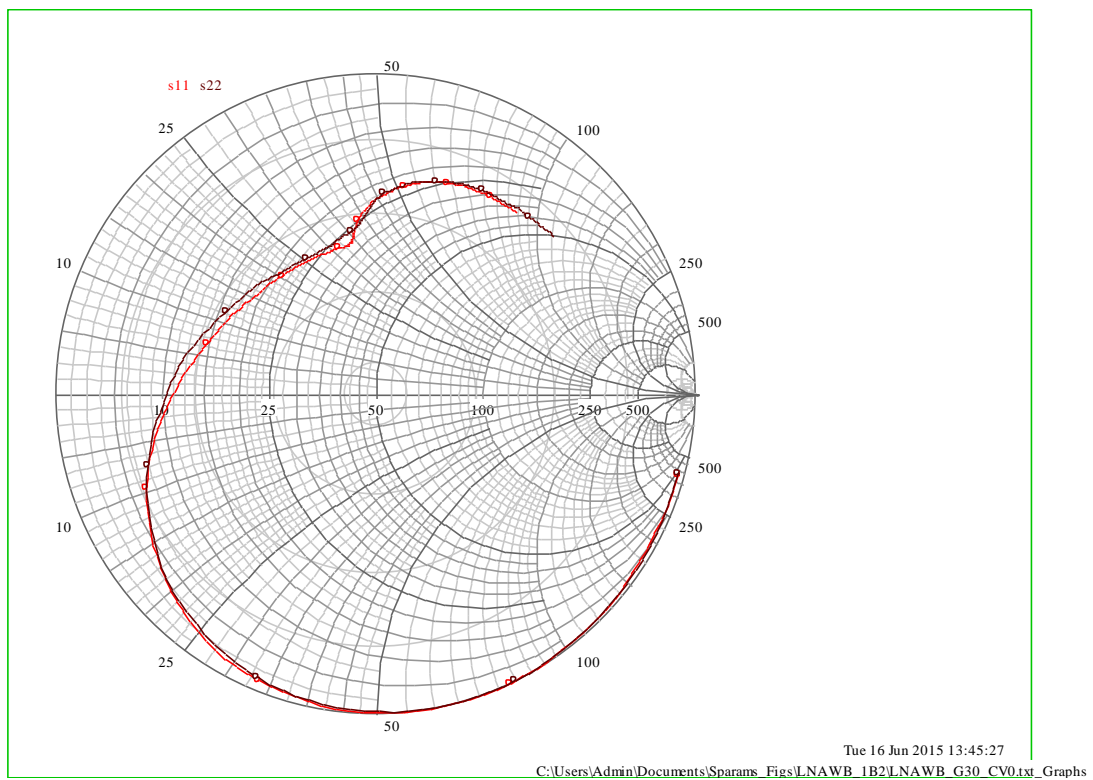


Figure 203 LNAWB Sample=2 Gain=31, Cap_Var =0 Short=0

4.17 LNAW Channel B Sample 3

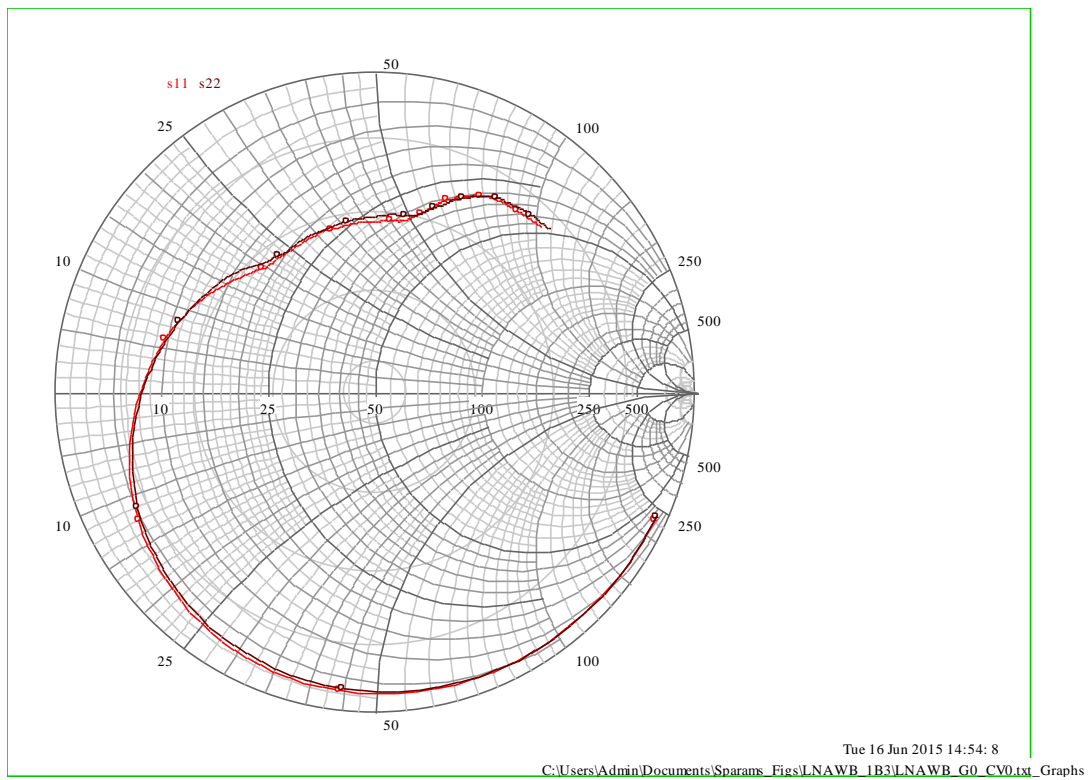


Figure 204 LNAWB Sample=3 Gain=0, Cap_Var=0 Short=0

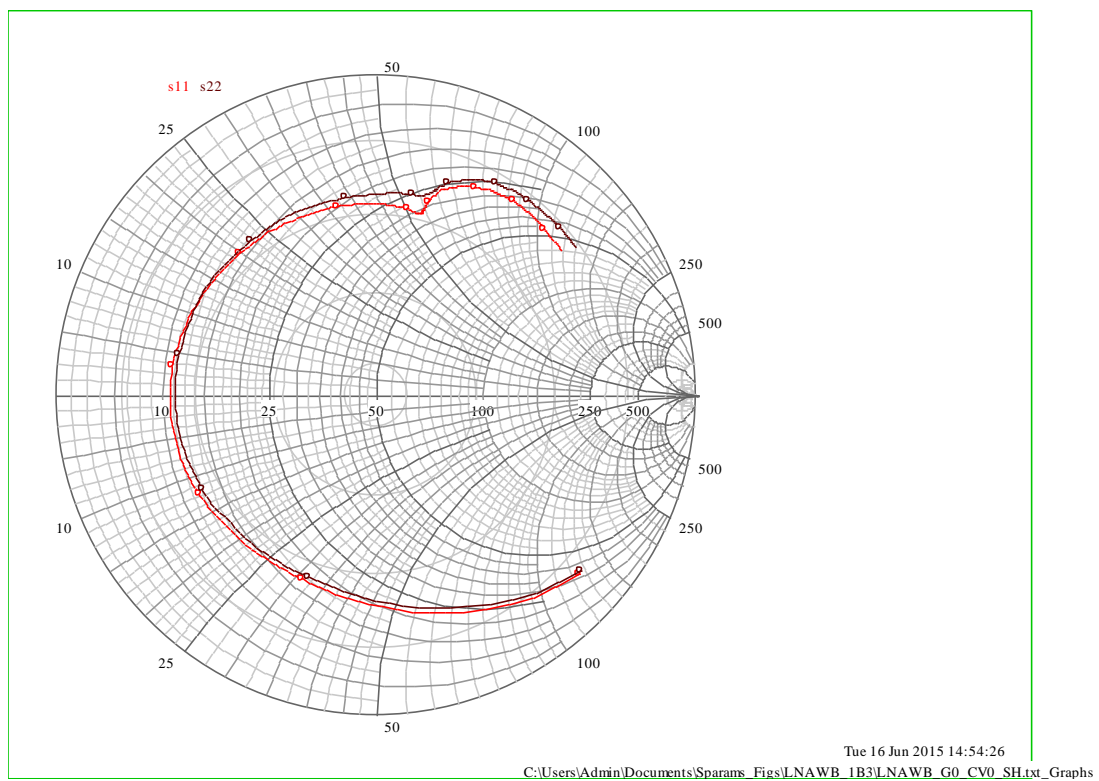
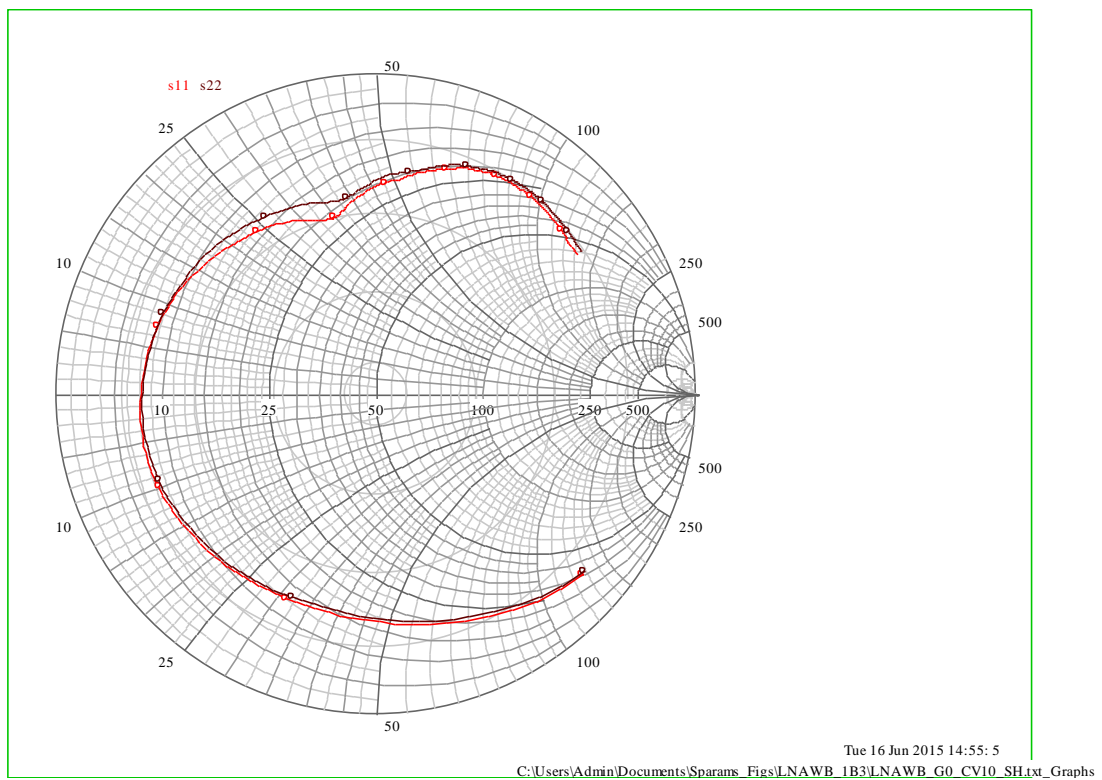
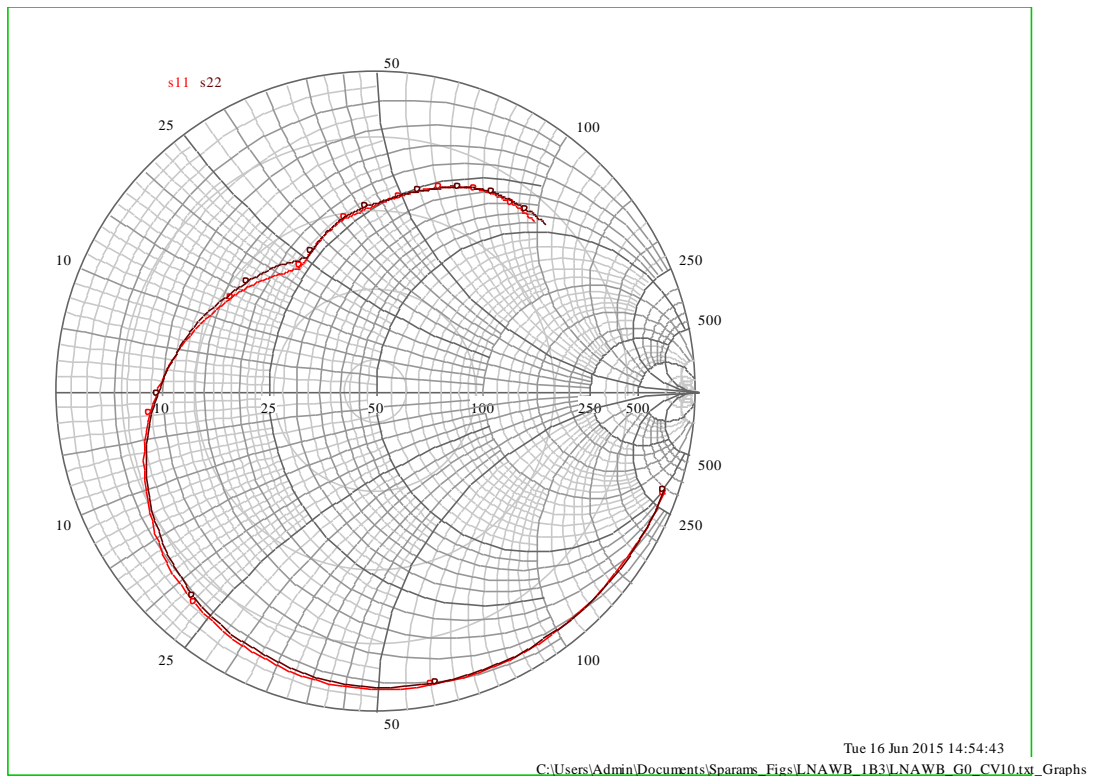


Figure 205 LNAWB Sample=3 Gain=0, Cap_Var=0 Short=1



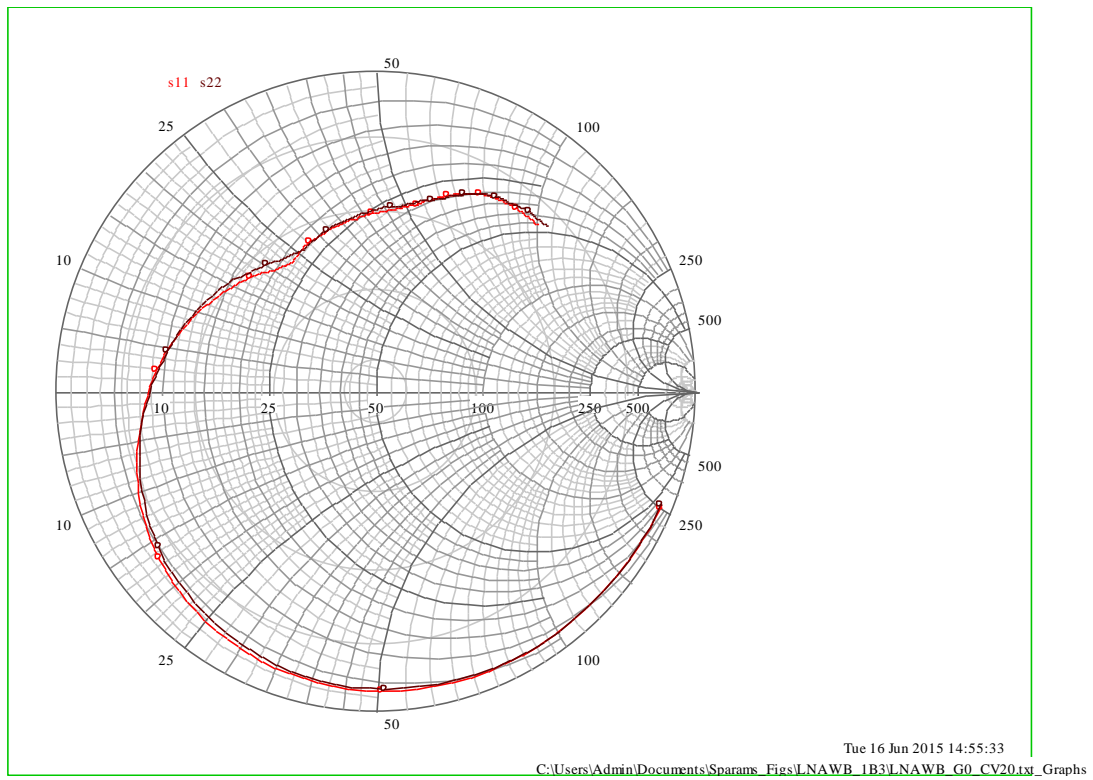


Figure 208 LNAWB Sample=3 Gain=0, Cap_Var =20 Short=0

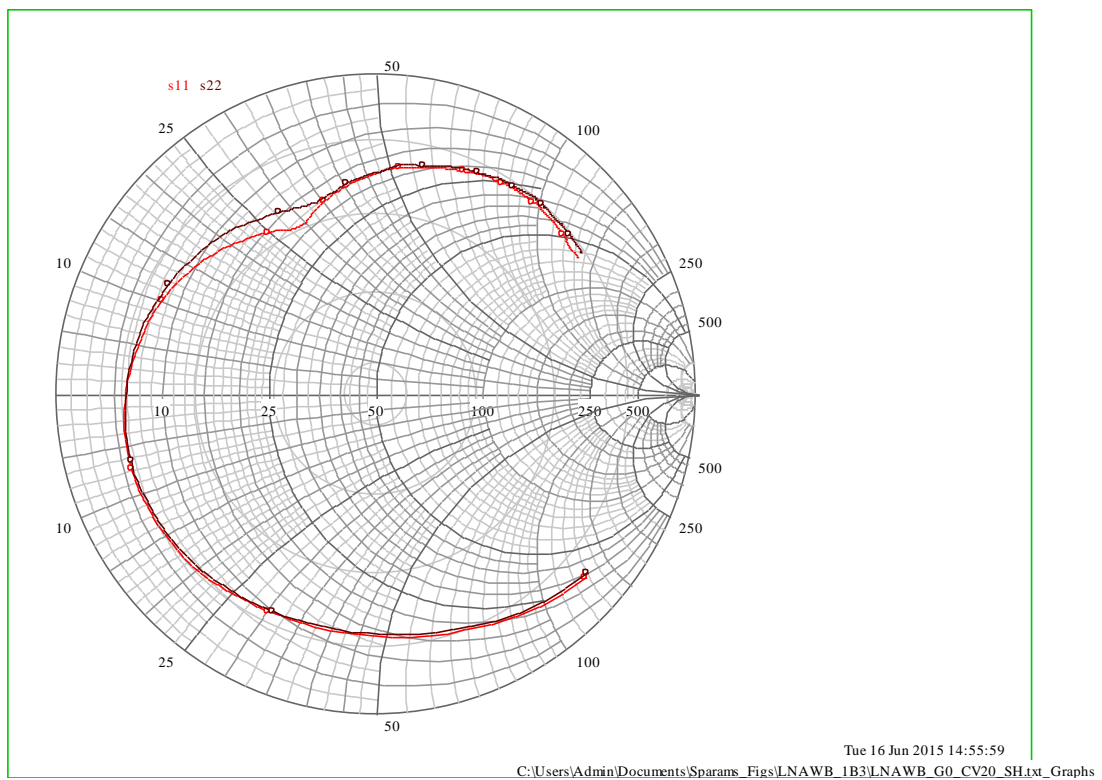


Figure 209 LNAWB Sample=3 Gain=0, Cap_Var =20 Short=1

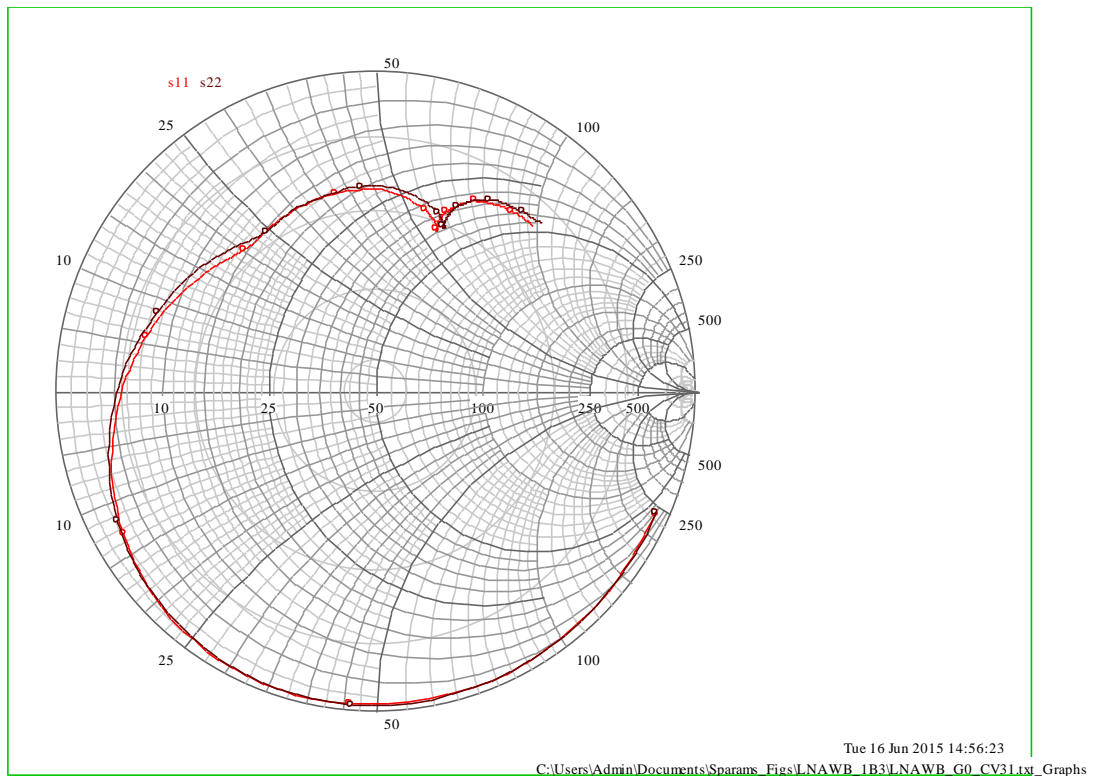


Figure 210 LNAWB Sample=3 Gain=0, Cap_Var =31 Short=0

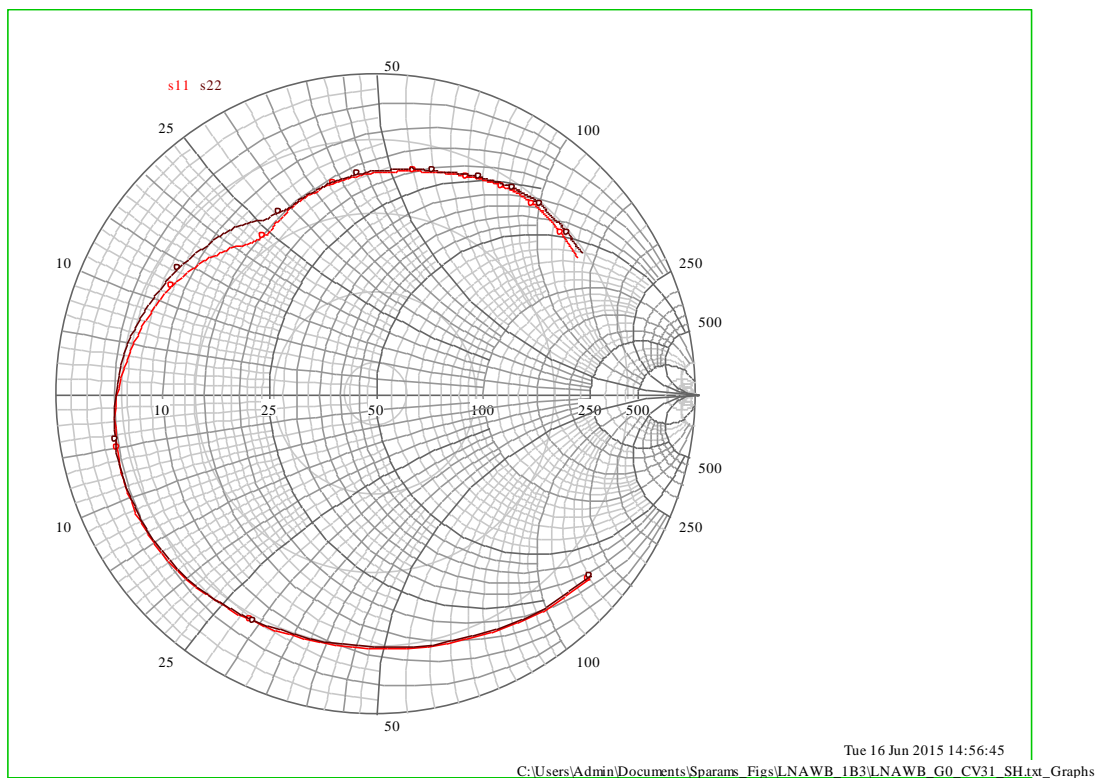


Figure 211 LNAWB Sample=3 Gain=0, Cap_Var =31 Short=1

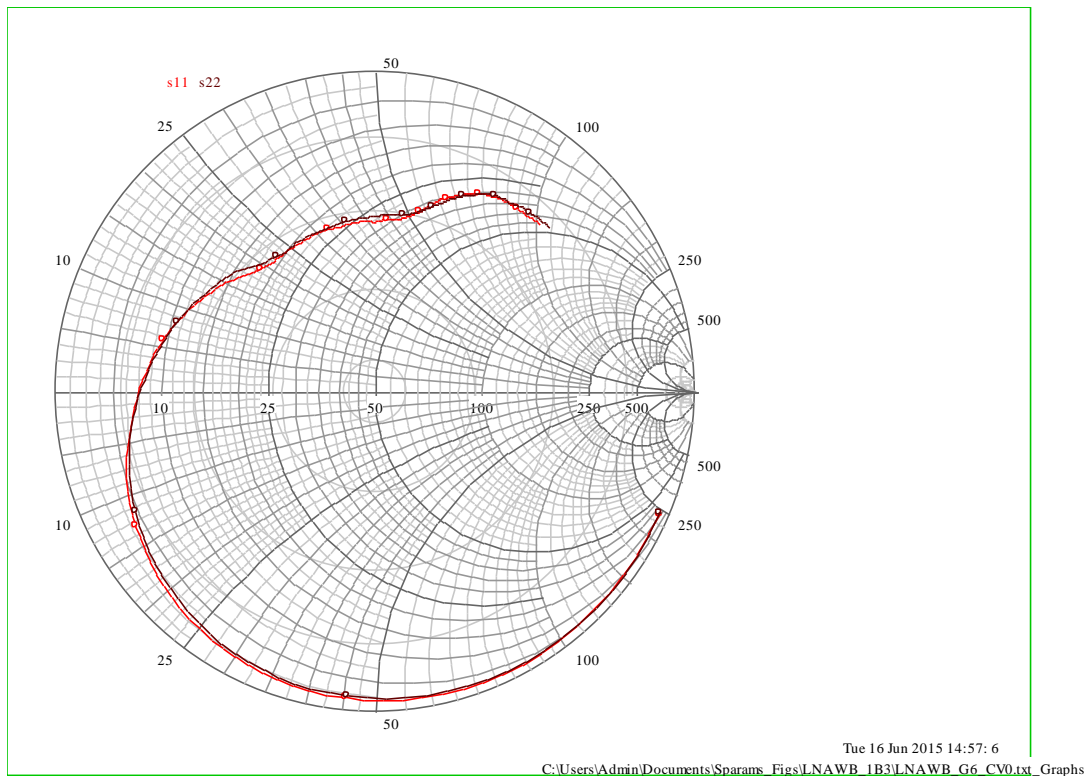


Figure 212 LNAWB Sample=3 Gain=6, Cap_Var =0 Short=0

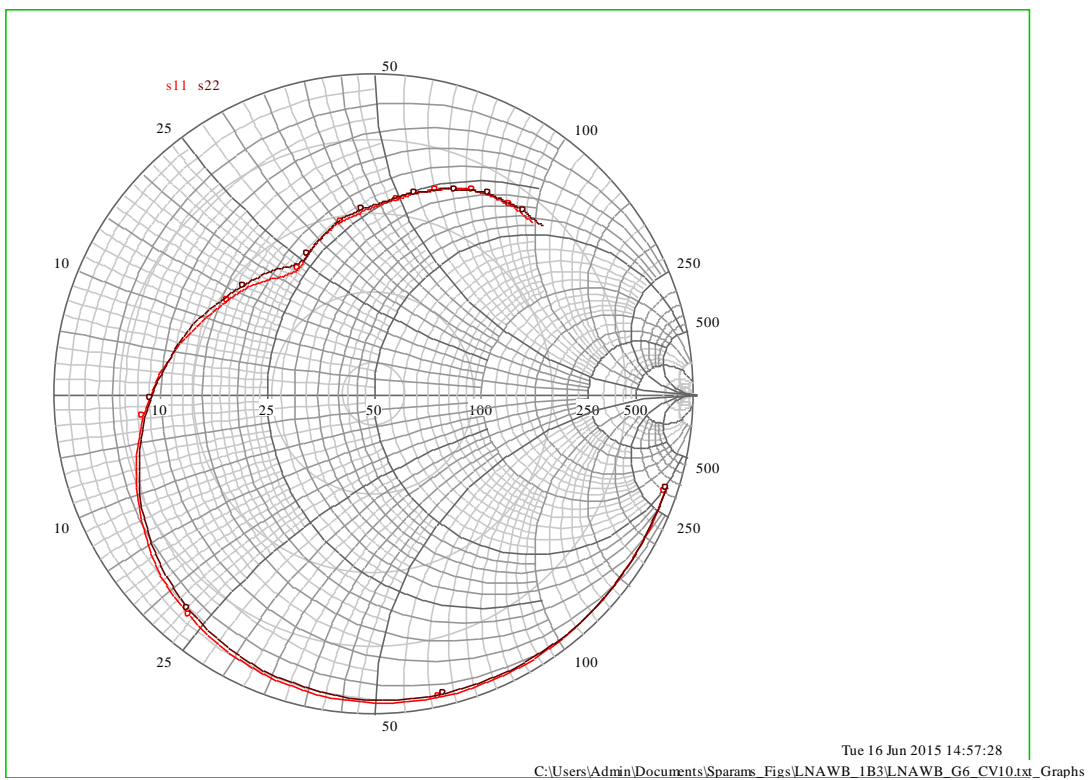


Figure 213 LNAWB Sample=3 Gain=6, Cap_Var =10 Short=0

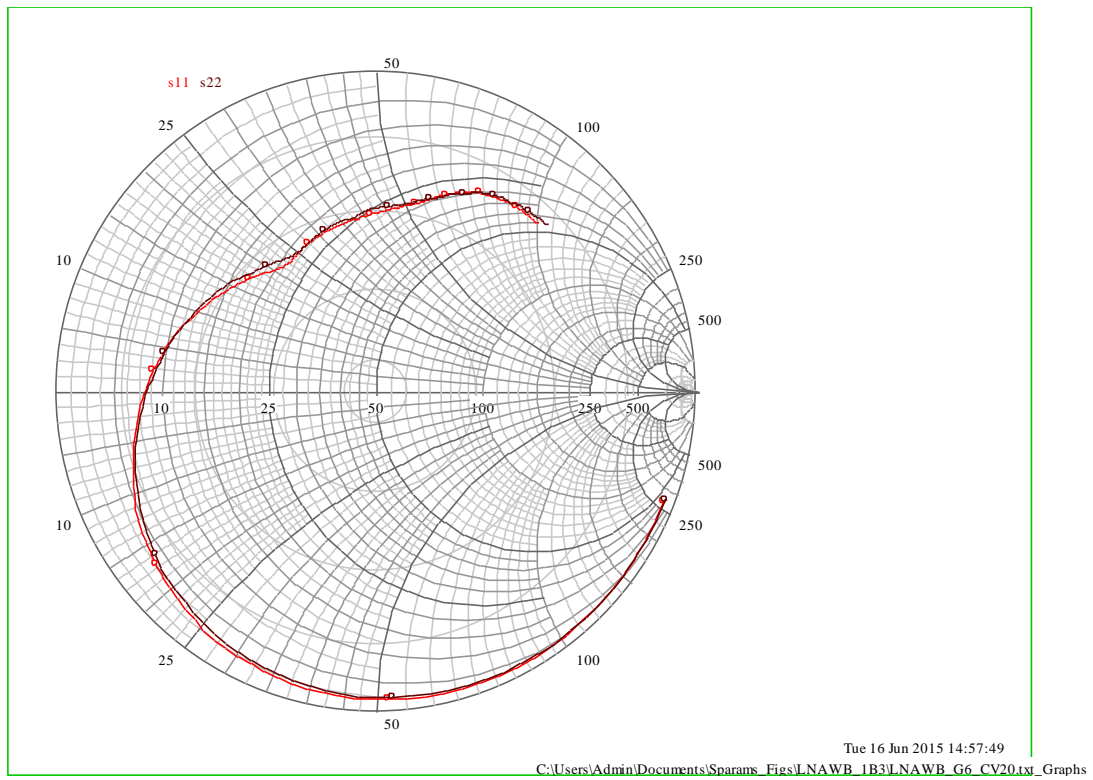


Figure 214 LNAWB Sample=3 Gain=6, Cap_Var =20 Short=0

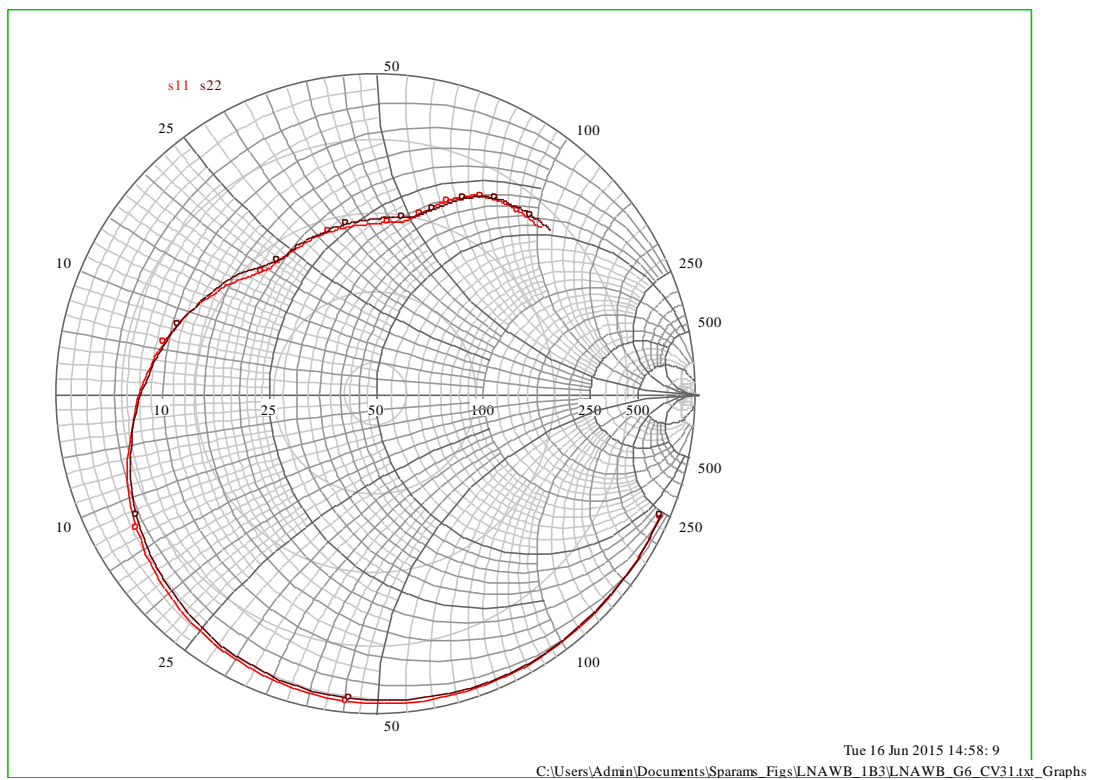


Figure 215 LNAWB Sample=3 Gain=6, Cap_Var =31 Short=0

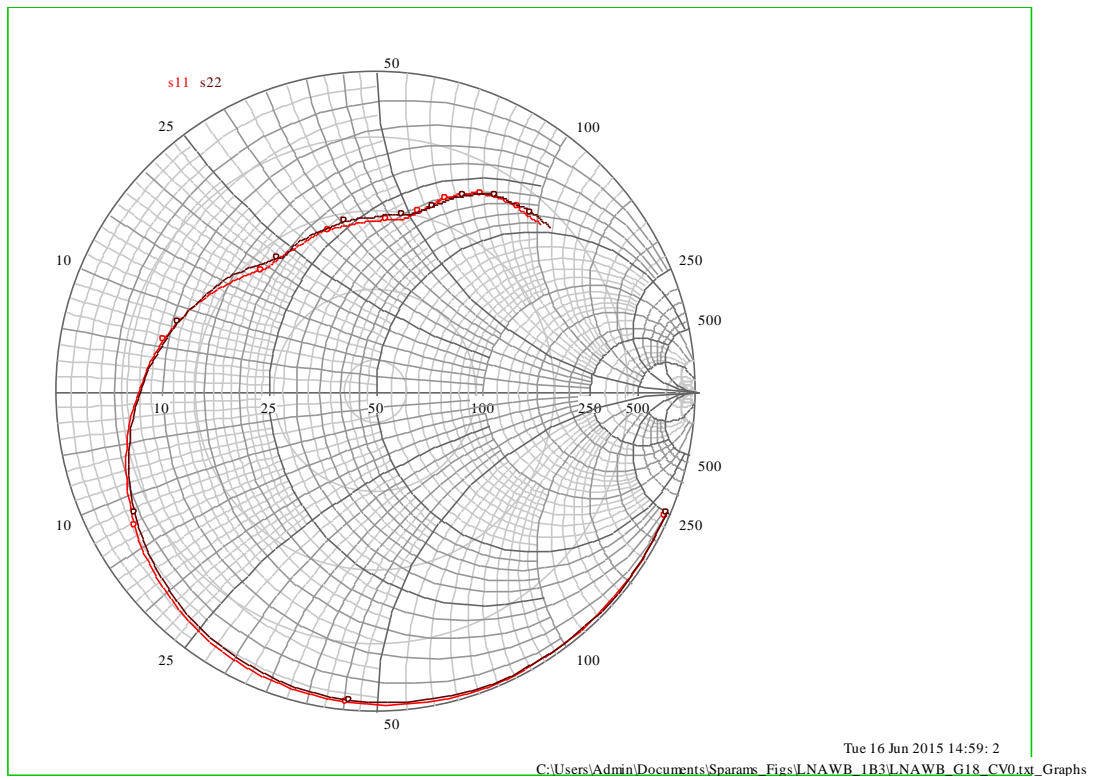


Figure 216 LNAWB Sample=3 Gain=18, Cap_Var =0 Short=0

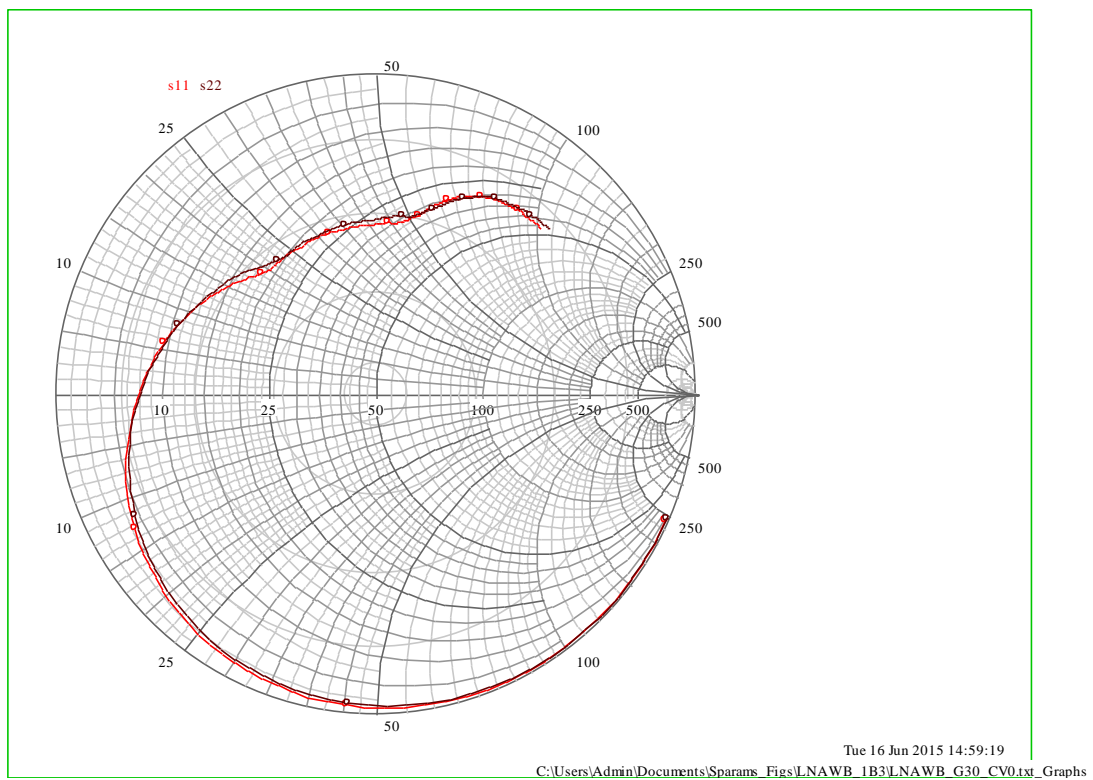


Figure 217 LNAWB Sample=3 Gain=31, Cap_Var =0 Short=0