Equivalent Circuits of Small Size Chip Resistors up to 50 GHz

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1. Abstract

The analysis and design of microwave circuits incorporating passive elements requires suitable equivalent circuit models that can be used to properly represent the components in CAD programs, including their parasitic effects, in the frequency range of interest. Ideally, these models should be as simple as possible and based on basic lumped elements whenever possible. We present here the models obtained in our laboratory for several types of small size (0102, 0202 and 0302) chip resistors of the type used for bonding in cryogenic microwave amplifiers. The resistors were manufactured by SOTA (State of the Art, Inc.) and Compex.

2. Introduction

In addition to the inductance of the connecting bonding wires, the small chip resistors used in cryogenic amplifiers present some parasitic elements which limit their performance. These parasitics depend on the size, layout and dielectric material used. The results of five different resistors are presented in this document. They are typical examples of thick and thin film types deposited on alumina and fused quartz substrates. The equivalent circuit has been obtained by comparison with the experimental measurements of the S parameters in a configuration that mimics the typical assembly method used in the amplifiers. The chip resistors are mounted on a copper plate and connected with short bonding wires to coplanar to microstrip transitions (figure 2) on both sides. The measurements were carried out in the 0.250-110 GHz frequency range at ambient temperature using a coplanar probe station.

3. Equipment

- Probe station mod. MPS 150 (Cascade Microtech)
- Coplanar probes mod. ACP 110-A-GSG-125 (Cascade Microtech)
- Vector network analyzer mod. PNA-X 5247 (Keysight)
- Millimeter wave controller mod. N5261A (Keysight)
- Millimeter wave heads mod. N5250CX10 (Keysight)
- Transitions from coplanar to microstrip mod. ProbePoint 0503 (Jmicro)
- Coplanar calibration substrate (ISS) mod. 104-783A (Cascade Microtech)

4. Calibration

The chip resistor measurements were obtained using a standard LRRM calibration performed with the Cascade Microtech ISS calibration substrate (Impedance Standard Substrate, figure 3) using WinCal software. With the standards used this calibration performs reasonably well in all the 250 MHz-110 GHz range sampled. It was verified with an open (probes in air) and with a long matched coplanar line (~27ps) in the ISS substrate. The ISS was used in combination with an absorbing ISS holder (SN 116-334) as recommended by Cascade.

The standard LRMM method yields a calibration referenced to the end of the coplanar probes. As the objective was to measure the resistors, the reference plane had to be shifted to the end of the coplanar-microstrip transitions. This was performed with a built-in feature of the PNA-X which allows de-embedding circuits characterized by their S-parameter files. Appendix I contain some information of the models used to generate the S-parameter files of the transitions. Additional information can be found in a previous Technical Report[1].

[1] J.D. Gallego, C. Diez González, I. López, I. Malo, "Effect of Source Bonding Wires in HEMT devices", CDT Technical Report 2016-18. http://icts-yebes.oan.es/reports/doc/IT-CDT-2016-18.pdf

5. Equivalent circuit results

The measurements were performed in the complete 250 MHz-110 GHz frequency range accessible to the measurement equipment. However, a good fit with a simple equivalent circuit could only be obtained in the 0-50 GHz range. The circuit used is presented in figure 1 and the values of the components for the different resistors are shown in table I.

The equivalent circuit fitted to the Compex resistors was intentionally forced to have the same values of the parasitic elements for all the resistances[2]. This allows using the same CAD equivalent circuit, changing only the numerical value of one component, for different resistors. During the fitting process it became clear that some of the parasitics have different importance depending on the resistor value. For example, L_ser is dominant for low resistor values while C has more influence for high values.

The value of the Q of the capacitor was introduced in an unfruitful attempt to obtain a better fit at f > 50 GHz. In the final version its value was fixed to 1000 (almost no loss), but it could be omitted (Q = ∞, lossless capacitor) if desired.

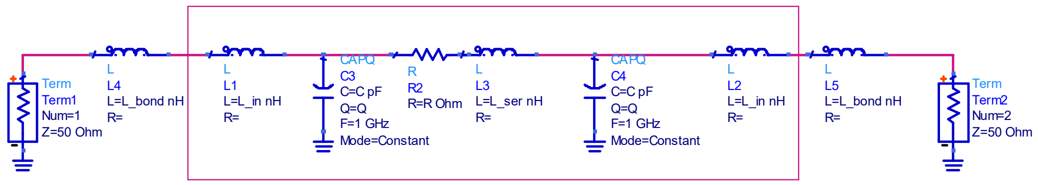


Figure 1: Equivalent circuit used for the resistors, including external bonding wires. The chip resistor intrinsic components are enclosed in the rectangle.

TABLE I

Parameters of the equivalent circuit of the resistors measured

R (Ohm)	Size (mil)	Type	L_ser (nH)	C (pF)	L_in (nH)	L_bond (nH)
10	20x10x10	Compex Thin, QZ	0.24	0.014	0.018	0.115
50	20x10x10	Compex Thin, QZ	0.24	0.014	0.018	0.115
100	20x10x10	Compex Thin, QZ	0.24	0.014	0.018	0.115
1000	20x10x10	Compex Thin, QZ	0.24	0.014	0.018	0.115
50	20x20x10	SOTA Thin, AL	0.10	0.048	0.014	0.115
50	30x20x15	SOTA Thick, AL	0.22	0.067	0.037	0.140

[2] The S parameters obtained with completely free parasitic elements are almost identical in the 50 GHz frequency range.

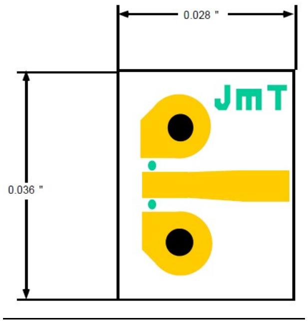


Figure 2: Drawing of Jmicro coplanar to microstrip transition used for the measurements.

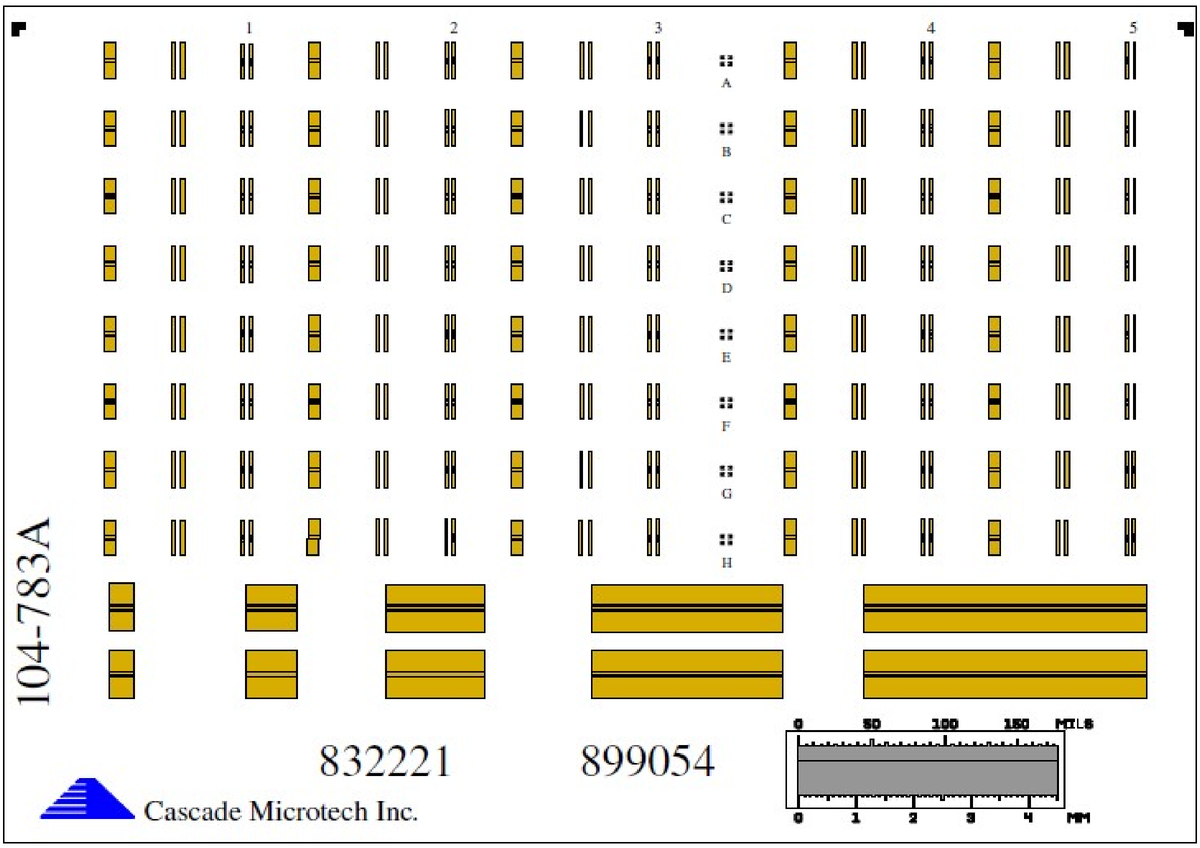
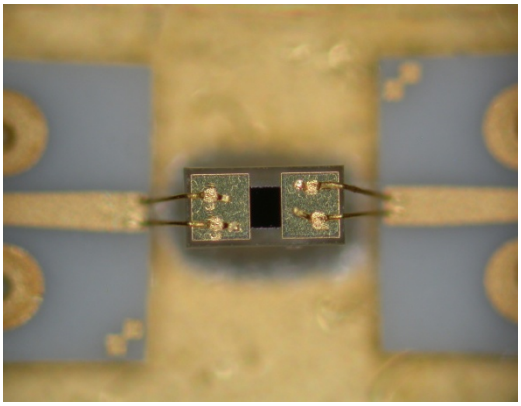
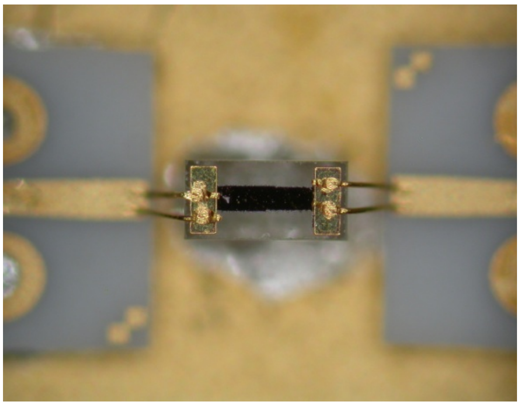


Figure 3: Calibration substrate used for LRRM calibration on the coplanar reference plane in the 0.250-110 GHz frequency range.

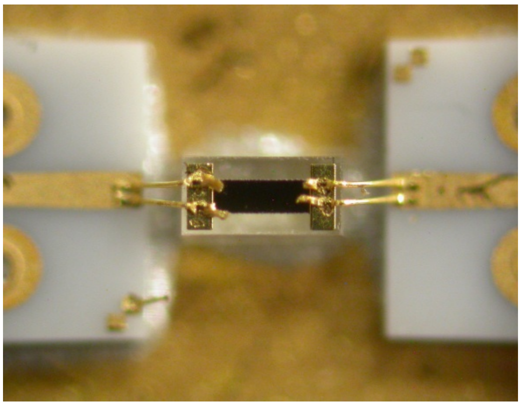
6. Photos



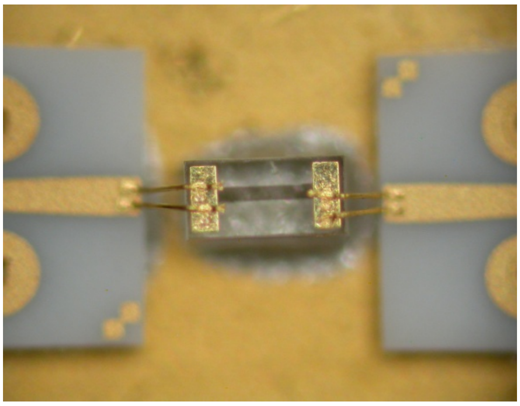
COMPEX 0102 10 Ohm (QUARTZ 10 mil)



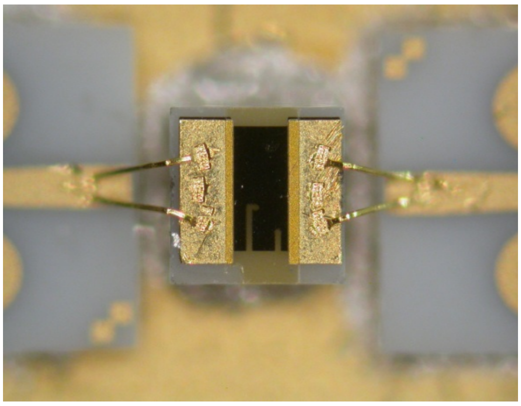
COMPEX 0102 50 Ohm (QUARTZ 10 mil)



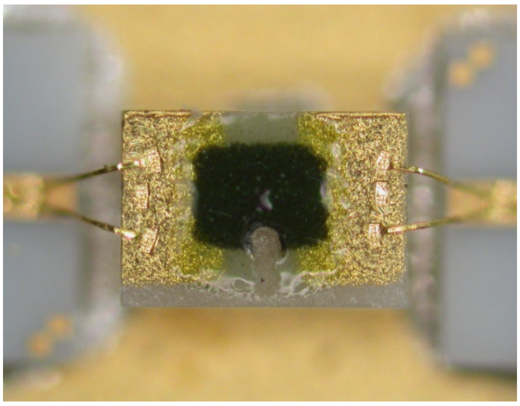
COMPEX 0102 100 Ohm (QUARTZ 10 mil)



COMPEX 0102 1K Ohm (QUARTZ 10 mil)



SOTA 0202 50 Ohm (ALUMINA 10 mil)



SOTA 0302 50 Ohm (ALUMINA 15 mil)

7. Bonding wires

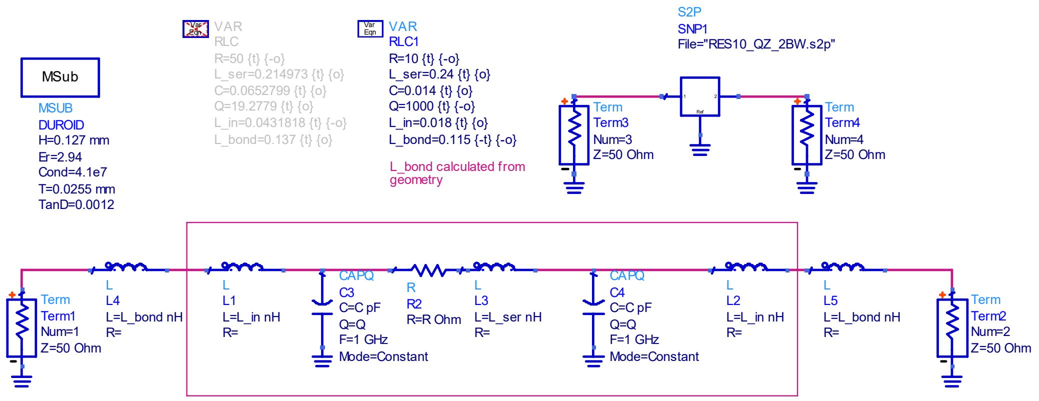
TABLE II

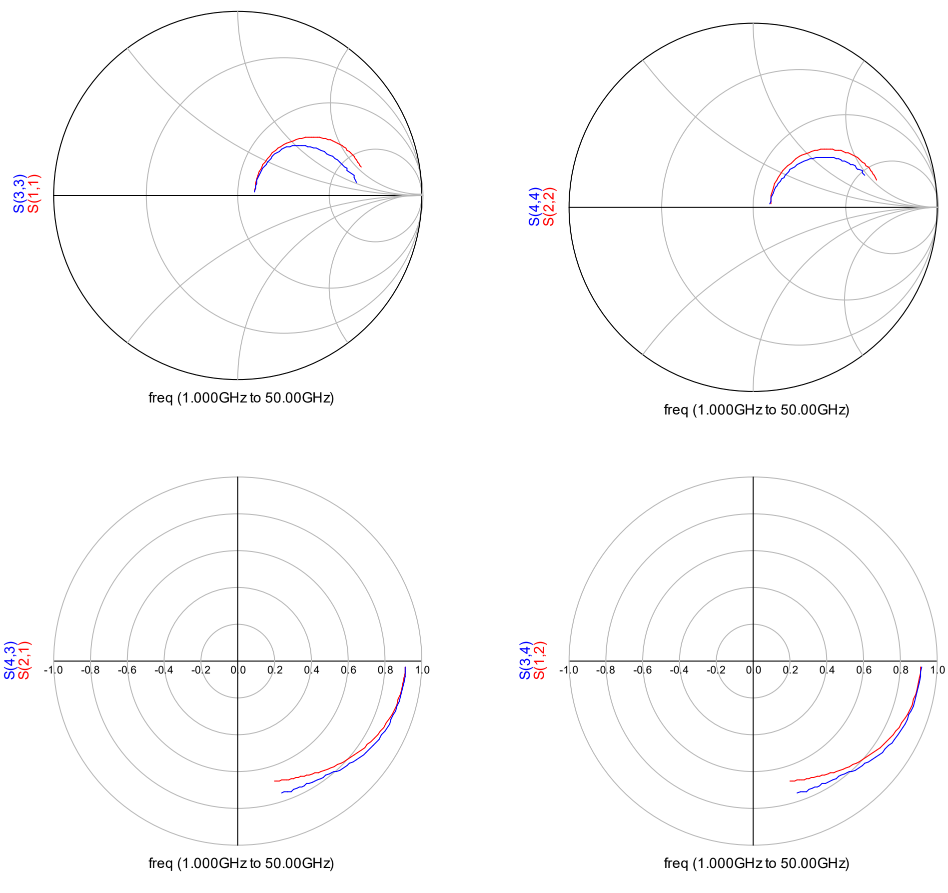
Length and separation of bonding wires

R (Ohm)	Type (Size)	Long BW 1 (um)	Sep BW 1 (um)	Long BW 2 (um)	Sep BW 2 (um)
10	0102	210	60-90	220	50-100
50	0102	160	30-90	180	60-80
100	0102	180	40-80	230	50-60
1000	0102	195	50-70	170	50-60
50	0202	250	50-150	250	50-150
50	0302	250	50-150	250	50-150

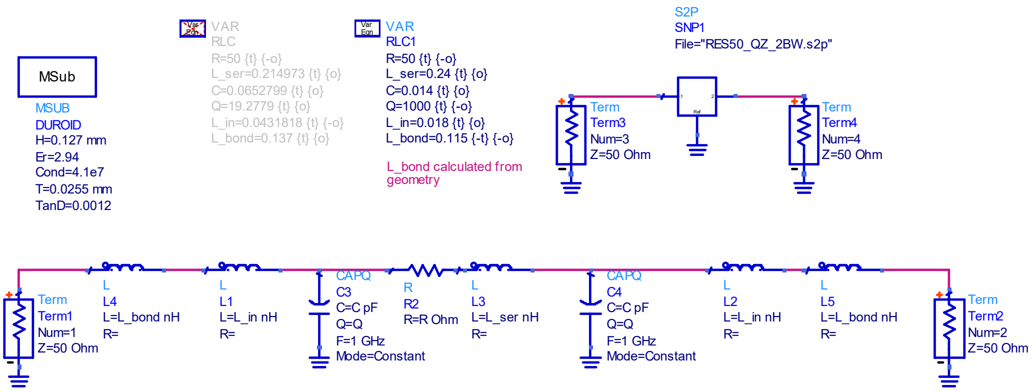
Maximum height of bonding wire over the resistor: 10 um
Bond wire diameter: 17.5 um

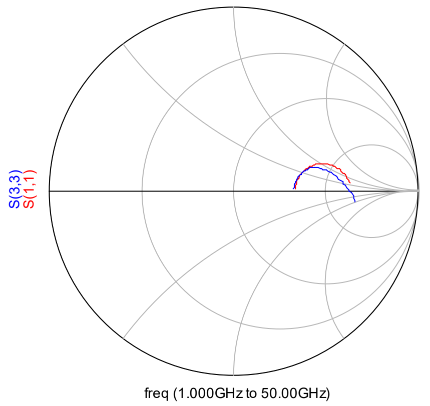
8. Model of COMPEX quartz 0102 resistor 10 Ohms

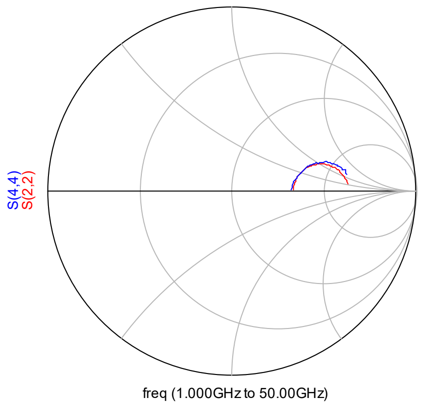


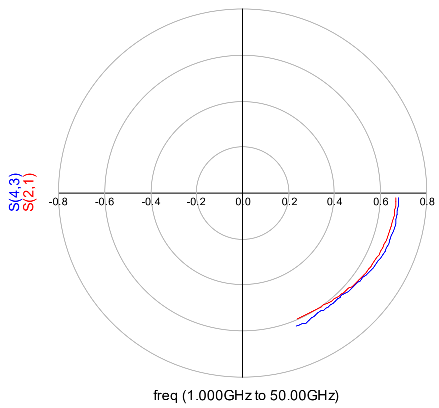


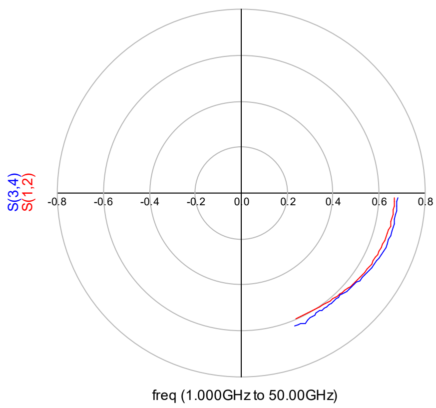
9. Model of COMPEX quartz 0102 resistor 50 Ohms



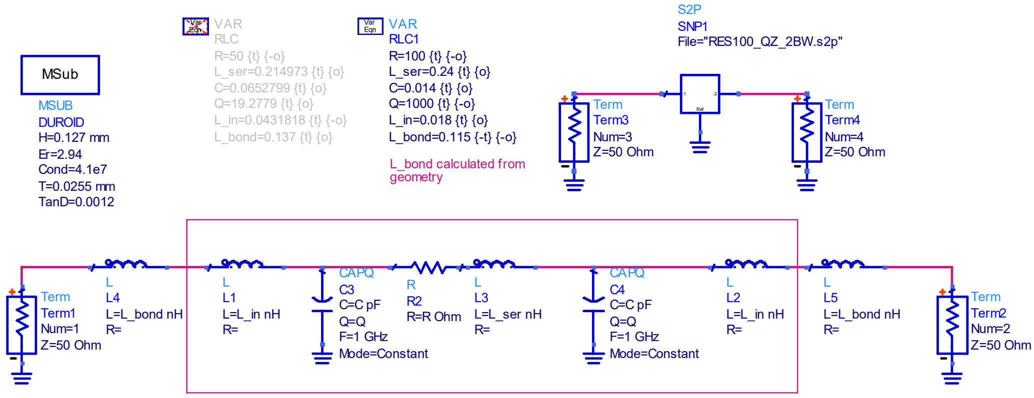


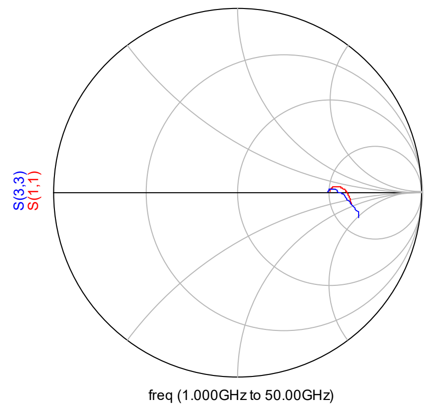


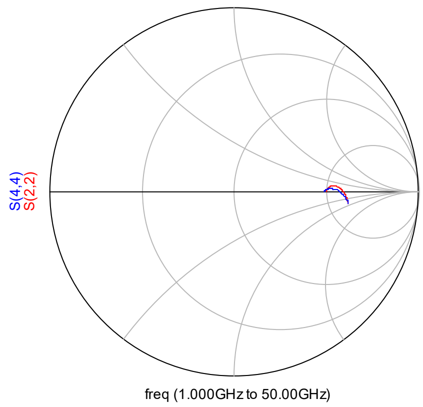


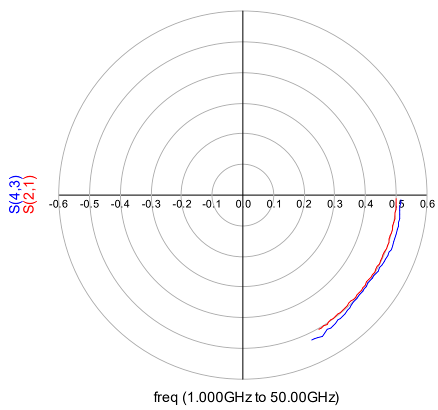


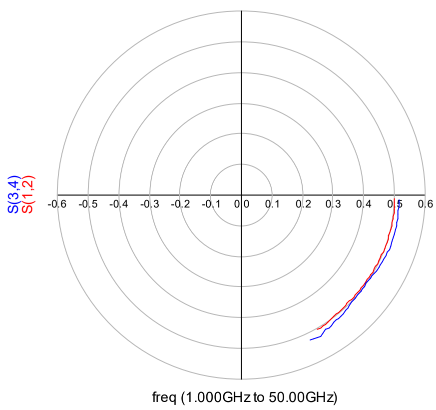
10. Model of COMPEX quartz 0102 resistor 100 Ohms



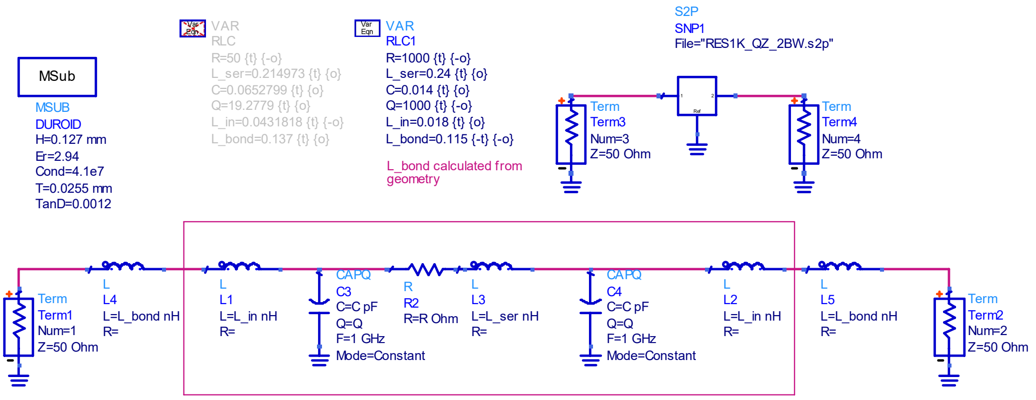


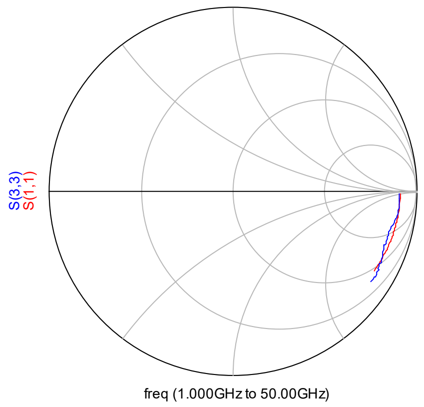


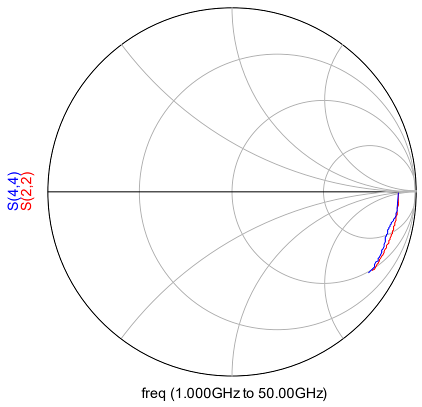


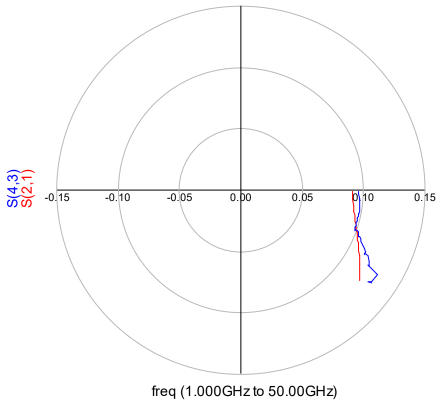


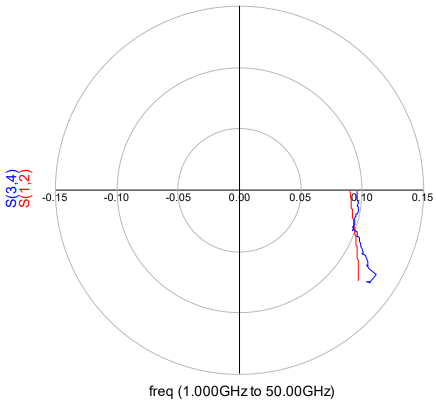
11. Model of COMPEX quartz 0102 resistor 1K Ohm



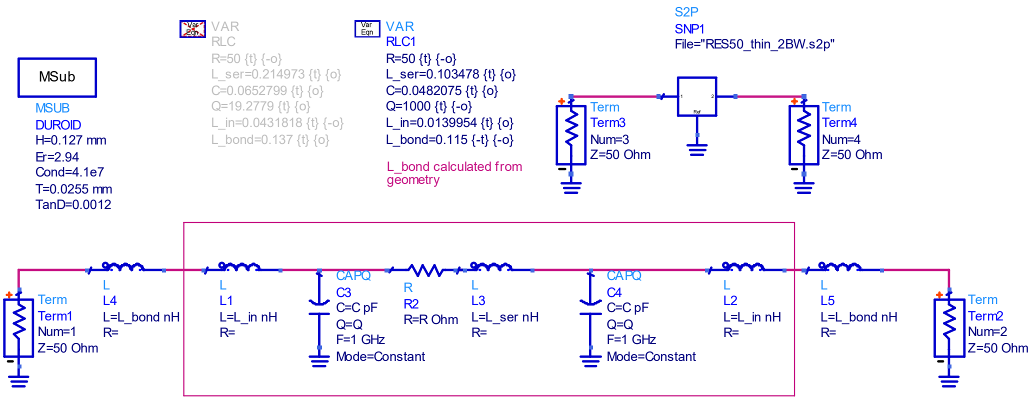


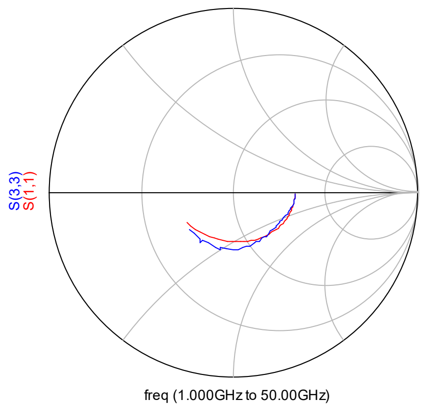


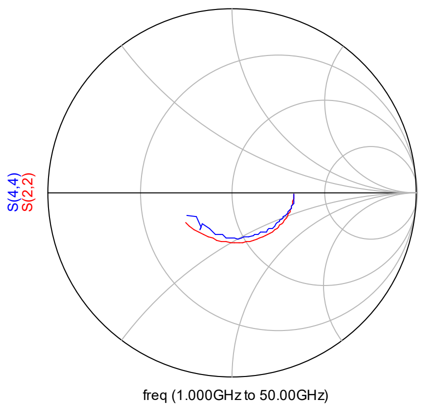


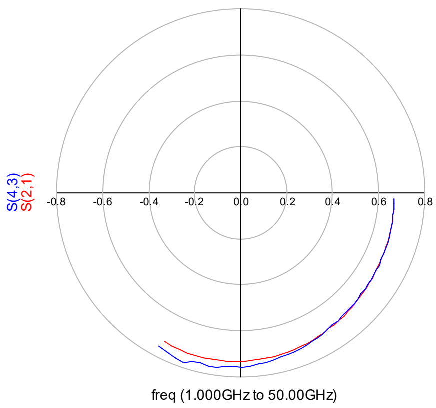


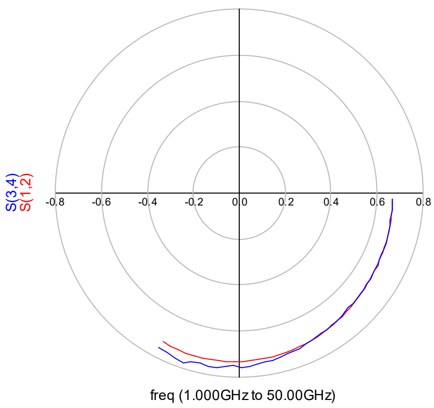
12. Models of SOTA alumina 0202 resistor 50 Ohms



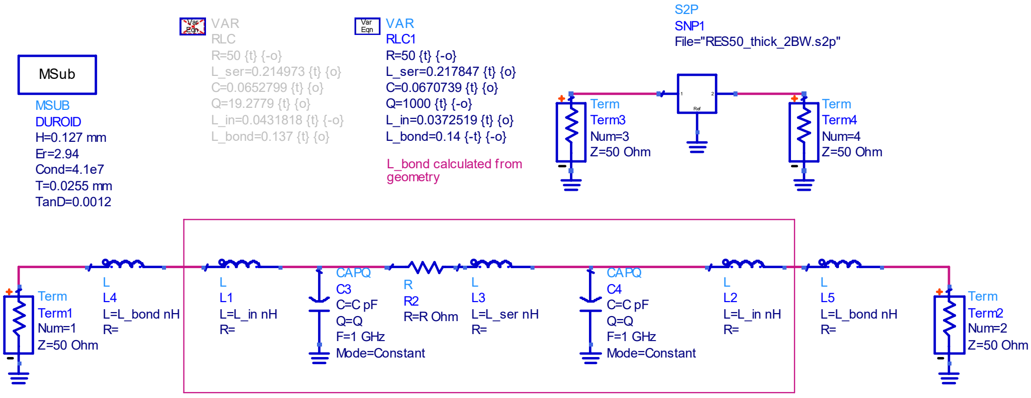


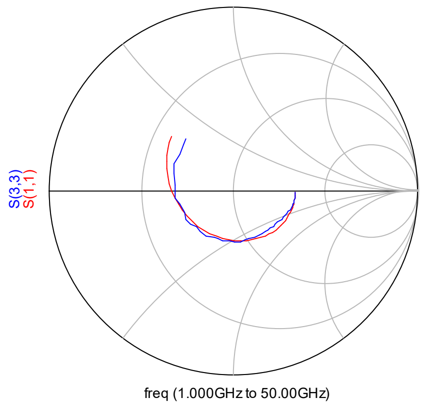


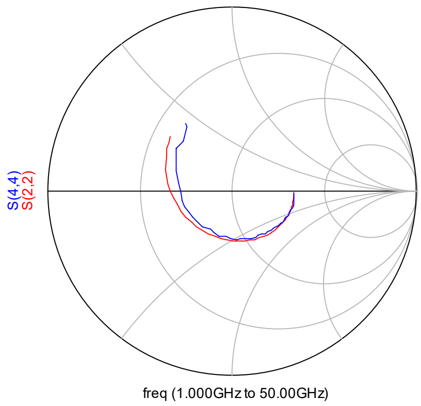


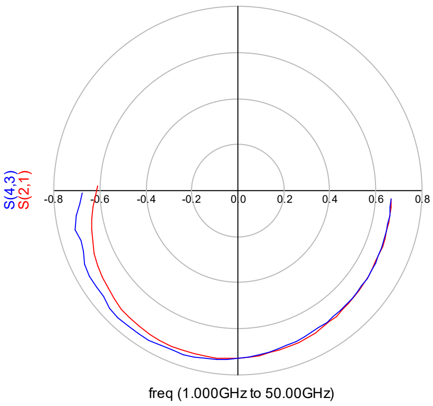


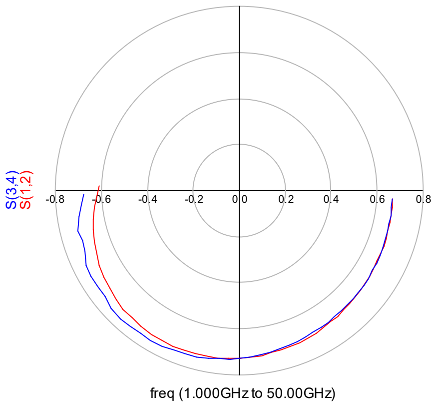
13. Models of SOTA alumina 0302 resistor 50 Ohms





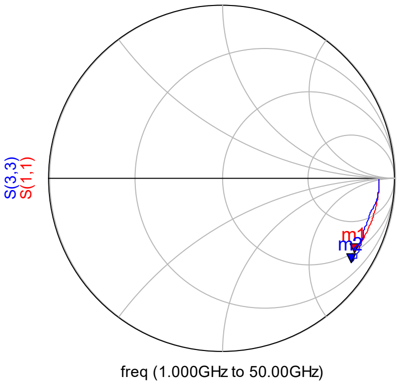


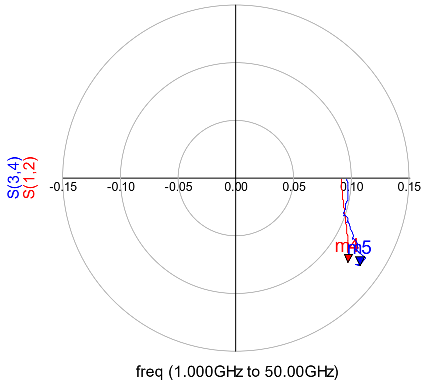




14. Models of COMPEX quartz 0102 resistor 1K Ohm (up to 50 and 100 GHz)

1) Up to 50 GHz
2) Up to 100 GHz



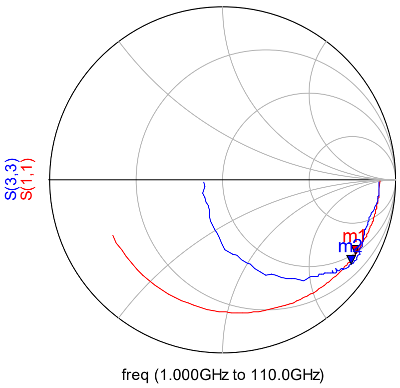


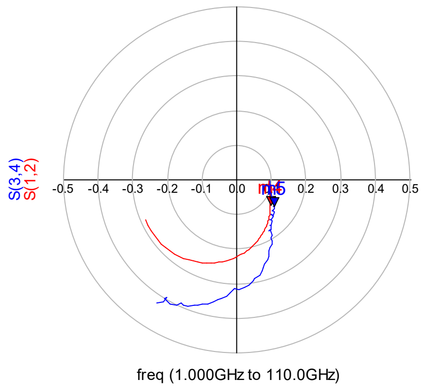
m1
freq=50.00GHz
S(1,1)=0.879 / -29.187
impedance = Z0 * (0.958 - j3.603)

m2
freq=50.00GHz
S(3,3)=0.890 / -32.993
impedance = Z0 * (0.695 - j3.240)

m4
freq=50.00GHz
S(1,2)=0.122 / -37.178

m5
freq=50.00GHz
S(3,4)=0.131 / -35.355





m1
freq=50.00GHz
S(1,1)=0.879 / -29.187
impedance = Z0 * (0.958 - j3.603)

m2
freq=50.00GHz
S(3,3)=0.890 / -32.993
impedance = Z0 * (0.695 - j3.240)

m4
freq=50.00GHz
S(1,2)=0.122 / -37.178

m5
freq=50.00GHz
S(3,4)=0.131 / -35.355

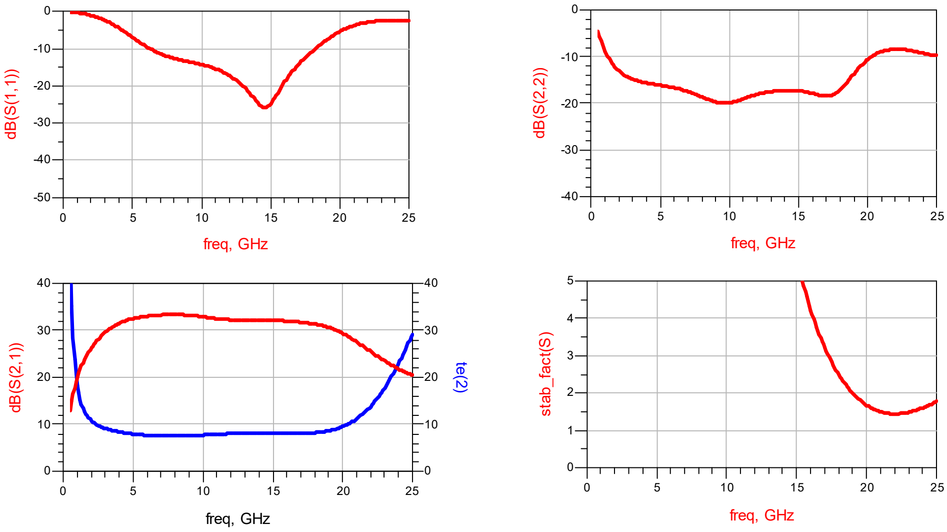
15. Effect of changing SOTA 0202 by COMPEX 0102 in 4-20 GHz ESO amplifier model.

≈ +2 dB of gain ≈ -0.4 K of noise

3) INITIAL:

Tn_mean	Tn_max	Tn_min
8.025	9.505	7.508

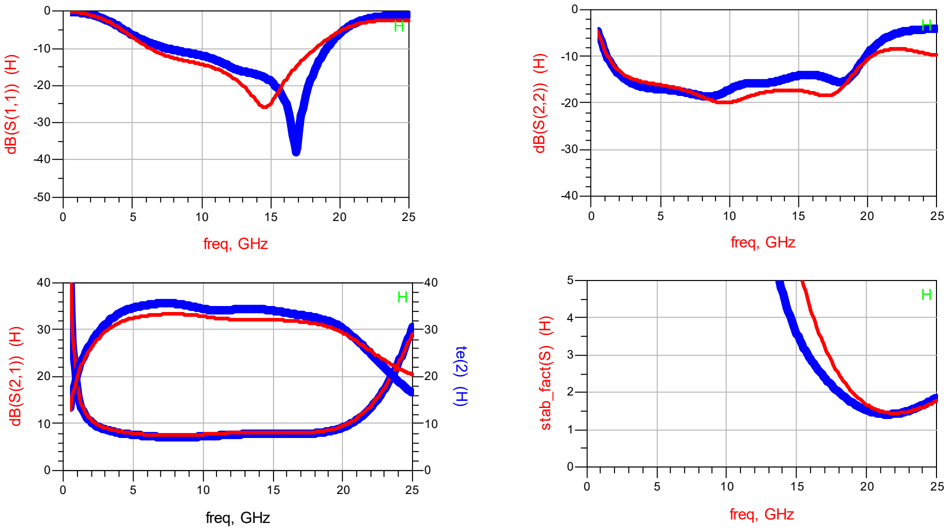
G_mean	G_rip_pp
32.197	3.968



4) WITH COMPEX 0102 RESISTORS (No tuning):

Tn_mean	Tn_max	Tn_min
7.676	9.202	7.083

G_mean	G_rip_pp
34.044	5.342



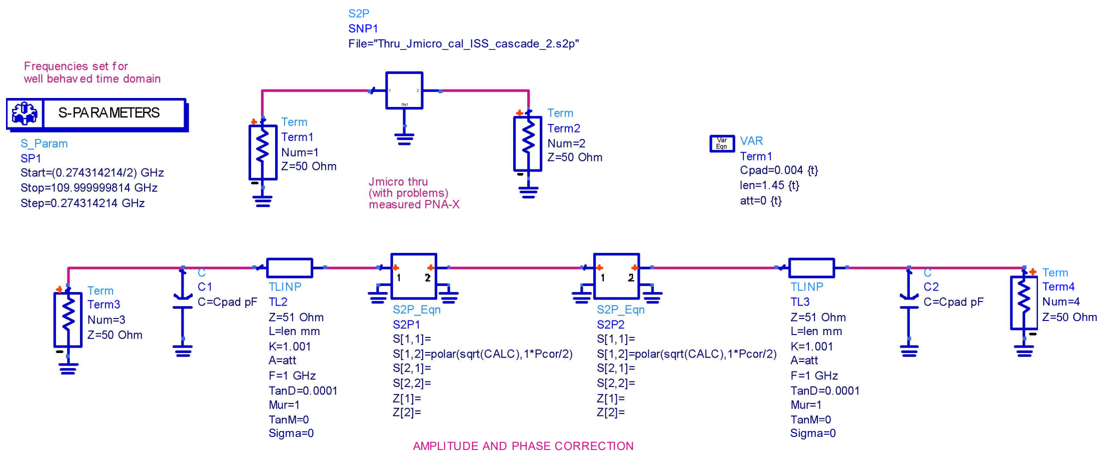
16. Conclusions

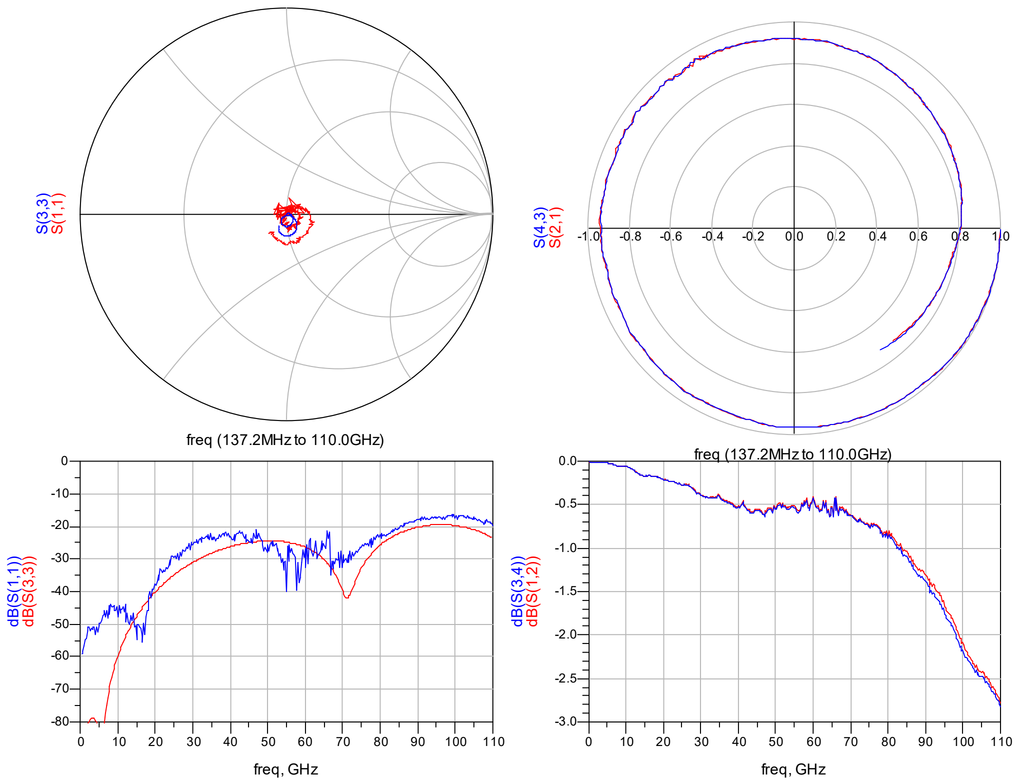
The results obtained show that a very simple circuit model for the resistors is a good approximation to the measurement up to 50 GHz, but significant differences appear at higher frequency (see example in section 14). It was not possible to fit to a simple model which could represent the component in the complete 110 GHz range measured. The new Compex 0102 quartz chip resistors show smaller parasitics than the larger SOTA alumina resistors, as can be easily seen by comparison of the S parameters of 50 Ohm resistors. The fact that the Compex parts are smaller and built on quartz substrates has a remarkable impact in the reduction of the parasitic capacitance. The effect of the parasitics may have an important influence in the performance of the amplifiers. As an example, section 15 presents the modeled effect of the substitution of all the 0202 SOTA resistors by 0102 Compex parts of the same value in a model of a wide-band amplifier (4-20 GHz ESO simple deign). An overall increase of 2 dB in gain and a reduction of 0.4 K in noise was observed, although the amplifier may need a re-optimization to perform a fair comparison.

17. Appendix I

Model used for de-embedding J-micro coplanar to microstrip transitions.

(Half of the model is used to generate S2P files used for de-embedding)





18. Appendix II: Datasheets

R Selection Charts

Note: Selection Charts are for guidance only. All Compex parts are built to specific customer requirements.

Microwave Resistance Range by Case Size (Ohms)

Case Size Mils	Min	Max
12X9	4	500
14X12	4	750
20X10	6	1000
15X15	4	1000
20X20	4	1250
30X20	4	2500
40X20	4	3750
30X30	2	2500
35X35	2	3000
40X40	2	3750
50X25	3	5000
60X30	3	5000
50X50	2	5000
60X60	2	5000
80X50	2	5000
100X50	2	5000
120X60	2	5000
100X100	2	5000

Standard Resistance Range by Case Size (Ohms)

Case Size Mils	Min*	Max Alumina	Max Silicon
12X9	1-3	25K	150K
14X12	1-3	40K	200K
20X10	1-3	60K	250K
15X15	1-2	70K	500K
20X20	1-2	125K	750K
30X20	1-2	200K	1M
40X20	1-2	250K	1.5M
30X30	1-2	275K	2M
35X35	1-2	300K	3M
40X40	1-2	500K	5M
50X25	1-2	300K	3M
60X30	1-2	500K	6M
50X50	1-2	700K	7M
60X60	1-2	2M	15M
80X50	1-2	2M	20M
100X50	1-2	2.5M	25M
120X60	1-2	3M	30M
100X100	1-2	3.5M	35M

Minimum Power Handling by Material and Size**

Case Size Mils	Alumina C-35	Silicon C-22	AIN C-28	BeO C-25	Quartz C-20
12X9	50 mW	50 mW	200 mW	400 mW	10 mW
14X12	100 mW	100 mW	400 mW	800 mW	20 mW
20X10	100 mW	100 mW	400 mW	800 mW	20 mW
15X15	100 mW	100 mW	400 mW	800 mW	20 mW
20X20	250 mW	250 mW	1.0 W	2.0 W	50 mW
30X20	250 mW	250 mW	1.0 W	2.0 W	50 mW
40X20	250 mW	250 mW	1.0 W	2.0 W	50 mW
30X30	250 mW	250 mW	1.0 W	2.0 W	50 mW
35X35	250 mW	250 mW	1.0 W	2.0 W	50 mW
40X40	350 mW	350 mW	1.4 W	2.8 W	70 mW
50X25	350 mW	350 mW	1.4 W	2.8 W	70 mW
60X30	500 mW	500 mW	2.0 W	4.0 W	100 mW
50X50	500 mW	500 mW	2.0 W	4.0 W	100 mW
60X60	500 mW	500 mW	2.0 W	4.0 W	100 mW
80X50	500 mW	500 mW	2.0 W	4.0 W	100 mW
100X50	500 mW	500 mW	2.0 W	4.0 W	100 mW
120X60	750 mW	750 mW	3.0 W	6.0 W	125 mW
100X100	750 mW	750 mW	3.0 W	6.0 W	125 mW

Power Handling Codes

Watts	Code
10 mW	A
20 mW	B
50 mW	C
75 mW	D
100 mW	E
150 mW	F
250 mW	G
500 mW	H
750 mW	J
1 W	K
2 W	L
3 W	N
4 W	P
5 W	Q
10 W	S
15 W	T
20 W	V
25 W	W
50 W	X

*Min Value TCR 150 ppm for TaN and 25 ppm for NiC.
**Higher Power ratings available, please consult factory.

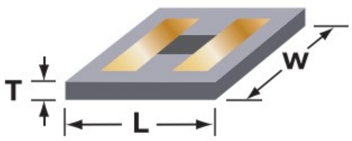
Bonding Pad Metallizations

Metallization		Code
Pd/Au Top Side	Bare Bottom Side	A
Pd/Au Top Side	Ta/Pd/Au Bottom Side	D
Pd/Au Top Side	Ti/Pt/Au Bottom Side	L
Ni/Au	Application Specific	P
TiW/Au Top Side	Bare Bottom Side	E
TiW/Au Top Side	Ta/Pd/Au Bottom Side	F
Window	Silicon Only	W
Custom	Application Specific	X

Temperature Coefficient of Resistance

Parts Per Million (PPM)	Code
±150	Q
±100	V
±50	W
± 25	X
±10	Y
±5	Z

R Chip Dimensions



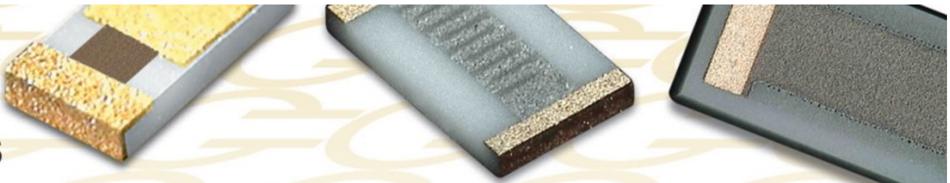
Testing Performed	Specification/Standard
Visual Inspection	MIL-PRF-55342 Para 4.8.1 MIL-STD-883 Method 2032
Mechanical Inspection	MIL-PRF-55342 Para 4.8.1
DC Resistance	MIL-PRF-55342 Para 4.8.2 MIL-STD-202 Method 303
Resistance Temperature Characteristic (TCR)	MIL-PRF-55342 Para 3.16 MIL-STD-202 Method 304
Short Time Overload	MIL-PRF-55342 Para 3.12
High Temperature Exposure	MIL-PRF-55342 Para 3.13
Thermal Shock	MIL-PRF-55342 Para 3.9 MIL-STD-202 Method 107
Resistance to Bonding Exposure	MIL-PRF-55342 Para 3.14.2
Wire Bonding Integrity	MIL-PRF-55342 Para 4.8.13
Life Test	MIL-PRF-55342 Para 3.17 MIL-STD-202 Method 108 (rated voltage @ 70°C for 2000 hours)

Performance Specifications

Typical Compex commercial testing includes 100% visual, mechanical, resistance, short time overload, and Resistance Temperature Characteristic. Our parts also meet or exceed additional MIL-PRF-55342 and MIL-STD-202 requirements outlined in the table at left. Please consult the factory for your exact testing requirements.

Higher power ratings, additional sizes, and custom resistors available. Please contact factory to request free samples.

Compex 17



R Series

Thin Film Resistors – Single or Dual Edge Wrap

Compex's line of wire-bondable and edge-terminated thin film resistors offers our customers significant flexibility to meet the most challenging designs. Built to the customer's exact specifications, available alternatives include single, dual, center-tap, array, and custom configurations. Standard and microwave frequency options up to 40 GHz or higher are available, voltage rating up to 100V.

- CUSTOM MANUFACTURED TO PROVIDE THE OPTIMUM PART FOR EACH APPLICATION
- ALUMINA, ALUMINUM NITRIDE AND BERYLLIUM OXIDE
- TOLERANCE DOWN TO 0.01%

R Part Number Assembly

Example shown: Compex Series R, Microwave Frequency, Dual edge-wrap SMT style TaN Resistor, C-28 (AlN), .040" x .020" x .010", 200Ω ± 2%, 150 PPM TCR, 1W

M T 1 - 28 - 40 x 20 x 10 - N - 200R0 - G - Q K

Resistor Style
M (Microwave)
R (Standard – DC to 500 MHz)

Resistive Metallization
T (Tantalum Nitride) or
N (NiChrome)

Number of Resistors per Device

Material Type
See R Selection Charts (at right)

Length x Width (mils)
See R Chip Dimensions (at right)

Thickness (mils)
10 mil standard (exception 12 x 9 size, standard is 5 mils).
Other thicknesses available, please consult factory.

Bonding Pad Metallization
See R Selection Charts (at right)

Power Handling Code
from Table (at right)

Temperature Coefficient
of Resistance (TCR)
See R Selection Charts (page 17)

Resistance Tolerance
See R Resistance Tolerance Codes (below)

Resistance (Ω)
First 4 digits represent significant figures and the last, the number of zeros to follow. When required, the "R" is used as a decimal point and the succeeding digit represents significant figures only. e.g.: 10001 = 10000 Ω, 10000 = 1000 Ω, 100R5 = 100.5 Ω

Note: Standard dimensional tolerance for length and width is ± 2 mils. The thickness tolerance is ± 1 mil.

Standard Resistance Tolerance Codes

Tolerance	Code	Tolerance	Code	Tolerance	Code	Tolerance	Code
± 20%	M	± 5%	J	± 1%	F	±.05%	Q
± 15%	L	± 3%	H	± .5%	D	±.01%	S
± 10%	K	± 2%	G	±.1%	B		

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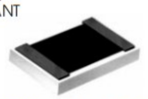
State of the Art, Inc.

0202 Thin Film Chip Resistor

Standard Grade, Surface Mount, Solderable

PROTECTIVE ENCAPSULANT

PRECISION THIN FILM RESISTOR



99.6% ALUMINA CHIP

FEATURES

- Tolerances to ± 0.1%
- Operating temperature range : -55° C to +150° C
- For high-density hybrid circuits where space is at a premium
- TCR's to ± 25 ppm
- Made with the same materials and process as our MIL-PRF-55342 "S" level qualified chips
- Delivers greater power handling capability with lighter weight construction

PERFORMANCE CHARACTERISTICS

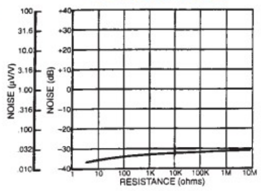
Resistance Range	5Ω –35KΩ
Tolerances	0.1%, 0.25%, 0.5%, 1%, 2%, 5%, 10%
Maximum Power	25 mW
Maximum Voltage	20 Volts

ENVIRONMENTAL PERFORMANCE (1)

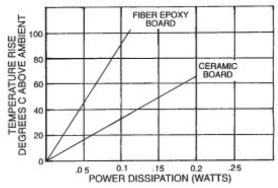
TCR (-55 to +125 °C in ppm/°C)	< 25 ppm
Thermal Shock	±0.02%
Low Temperature Operation	±0.02%
Short-time Overload	±0.02%
Resistance to Bonding Exposure	±0.02%
Moisture Resistance	±0.03%
High Temperature Exposure	±0.03%
Life	See Chart

(1) Typical resistance change, the maximum is the same as MIL-PRF-55342. Test methods are per MIL-PRF-55342.

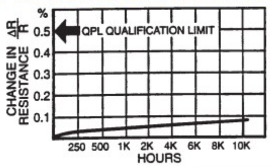
CURRENT NOISE



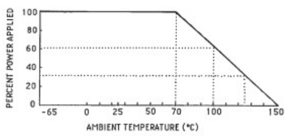
POWER DISSIPATION



TYPICAL LIFE TEST PERFORMANCE



POWER DERATING



PART NUMBERING

S0202AA 150 J H W

- Termination Material
  W: Gold
- TCR
  E: ±25 ppm H: ±50 ppm K: ±100 ppm
- TOLERANCES
  B: 0.1% C: 0.25% D: 0.5% F: 1% G: 2% J: 5% K: 10% M: 20%
- RESISTANCE VALUE
  Three or four digits are used with all leading digits significant. Four digits are used for 1% tolerance or lower, otherwise three digits are used. The last digit specifies the number of zeros to add. The letter "R" is used to represent the decimal for fractional ohmic values. Example: 5R6 is 5.6 ohms.
- Substrate Matieral A: Alumina Ceramic
- Termination Style A: Top Sided with Bottom Isolated

MECHANICAL

	INCHES	MM
Length	.020 (+.002/-.002)	.51 (+.05/-.05)
Width	.020 (+.002/-.002)	.51 (+.05/-.05)
Thickness	.009 - .011	.23 - .27
Top Term.	.004 - .006	.10 - .15

Approx. Weight .00043 grams

All product is tested IAW Mil-Std-202, method 208, including 8 hour steam aging.

PACKAGING

Two packaging options are available:

- Bulk Packaging - (5000 per Bag Max.)
- Waffle Pack - (400 per Tray Max.)

OPTIONS

SOTA offers a full line of component parts in the 0202 size including High-Reliability (customer specified testing). Available options are epoxy bondable and wire bondable terminations, and custom part marking.

STATE OF THE ART, INC. 2470 Fox Hill Road, State College, PA 16803-1797
Phone (814) 355-8004 Fax (814) 355-2714 **Toll Free 1-800-458-3401**

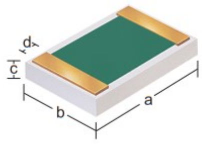
05/21/99

Where Quality Isn't a Goal...It's Our Tradition

State of the Art, Inc.

Semi-Precision Thick Film Chip Resistor

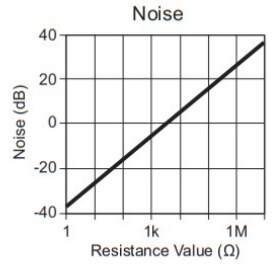
MIL-PRF-55342/13 Wire Bondable RM0302

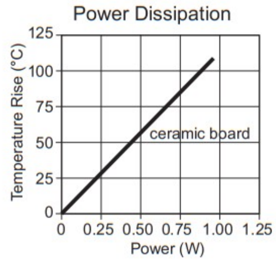


Performance

Resistance Range*	1Ω to 22 MΩ
Tolerances (± %)*	1, 2, 5, 10
TCR (± ppm/°C)*	100, 200, 300
Power Rating	40 mW
Voltage Rating	15 V
Operating Range	-65 to 150°C
Product Levels	M, P, R, S, U, V, T

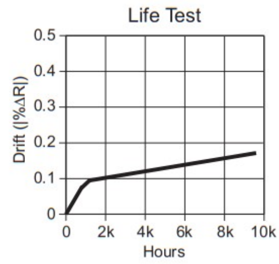
*see QPL55342 for part number availability

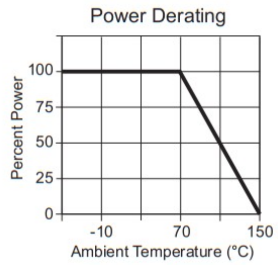




Maximum Allowable Drift

Temperature Characteristic	K	L	M
TCR (ppm/°C)	±100	±200	±300
Thermal Shock	±0.5%	±0.5%	±0.5%
Power Conditioning	±0.5%	±0.5%	±0.5%
Low Temperature Operation	±0.25%	±0.25%	±0.5%
Short Time Overload	±0.25%	±0.25%	±0.5%
High Temperature Exposure	±0.5%	±0.5%	±1.0%
Moisture Resistance	±0.5%	±0.5%	±0.5%
Life (Qualification)	±0.5%	±0.5%	±2.0%
Life (FR Level)	±2.0%	±2.0%	±2.0%
Resistance to Soldering Heat	±0.25%	±0.25%	±0.25%
Resistance to Bonding Exposure	±0.25%	±0.25%	±0.25%





Part Number

M55342K13W100DS -W

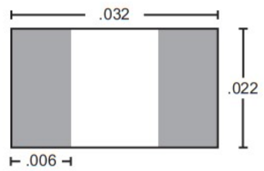
- Packaging: -TR: Tape & Reel -W: Waffle Tray
- Product Level (/1000 hrs.): M: 1% P: 0.1% R & U: 0.01% S & V: 0.001% T: Space 0.001%
- Resistance Value and Tolerance: Three numerals and a letter indicating decimal, value range, and tolerance
  - Ω: D: 1% G: 2% J: 5% M: 10%
  - kΩ: E: 1% H: 2% K: 5% N: 10%
  - MΩ: F: 1% T: 2% L: 5% P: 10%
- Termination Material: W: Wire Bondable Gold
- Size: 13: RM0302
- Temperature Characteristic (ppm/°C): K: ±100 L: ±200 M: ±300
- Performance Specification MIL-PRF-55342

Mechanical

	Inches	Millimeters
Length (a)	.032(.030 - .034)	0.81(0.76 - 0.86)
Width (b)	.022(.020 - .024)	0.56(0.51 - 0.61)
Thickness (c)	.015(.010 - .020)	0.38(0.25 - 0.51)
Top Termination (d)	.006(.004 - .008)	0.15(0.10 - 0.20)

Approximate Weight 0.00055 g

Nominal Bond Pads (inches)



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