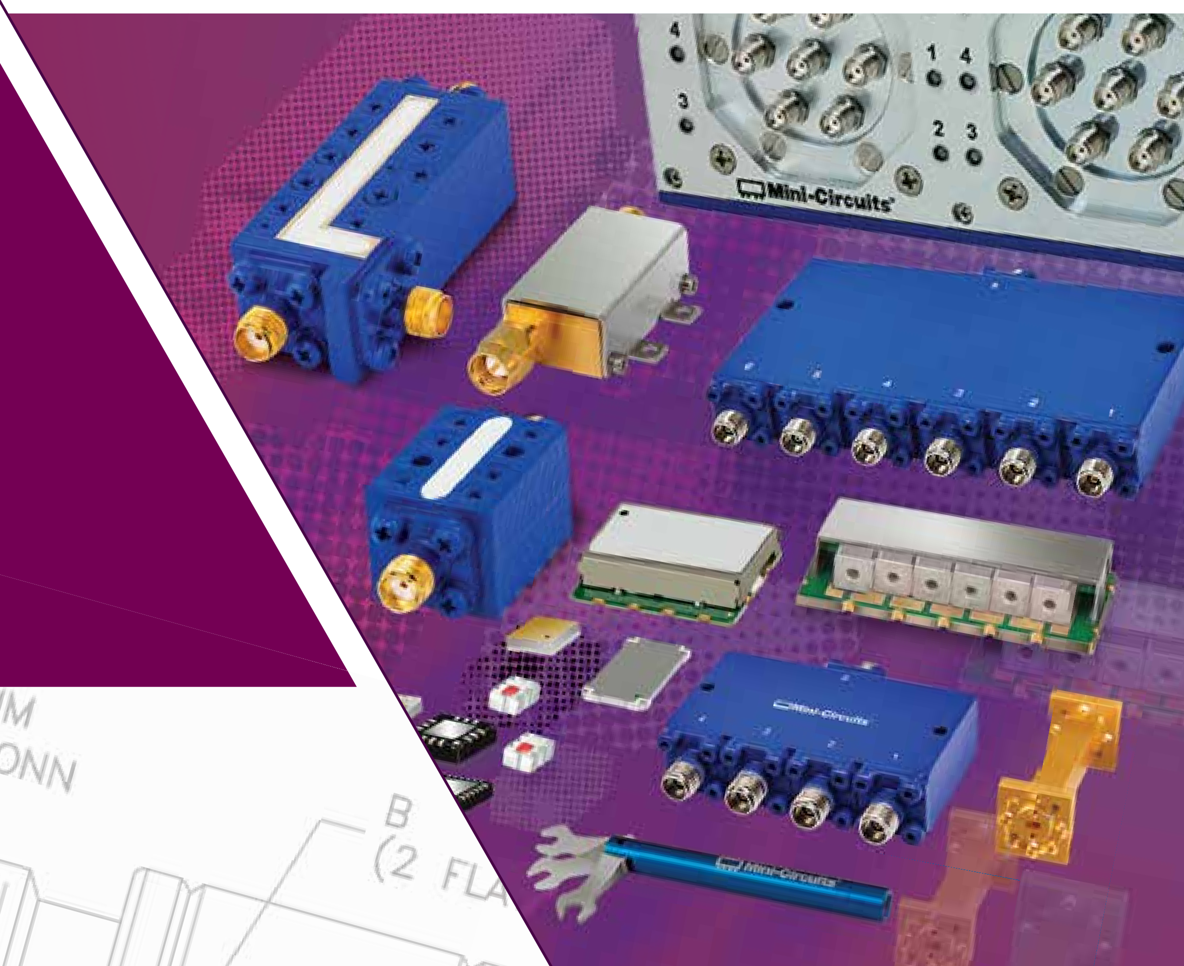
Mini-Circuits®

Q2 2019

NEW PRODUCT GUIDE



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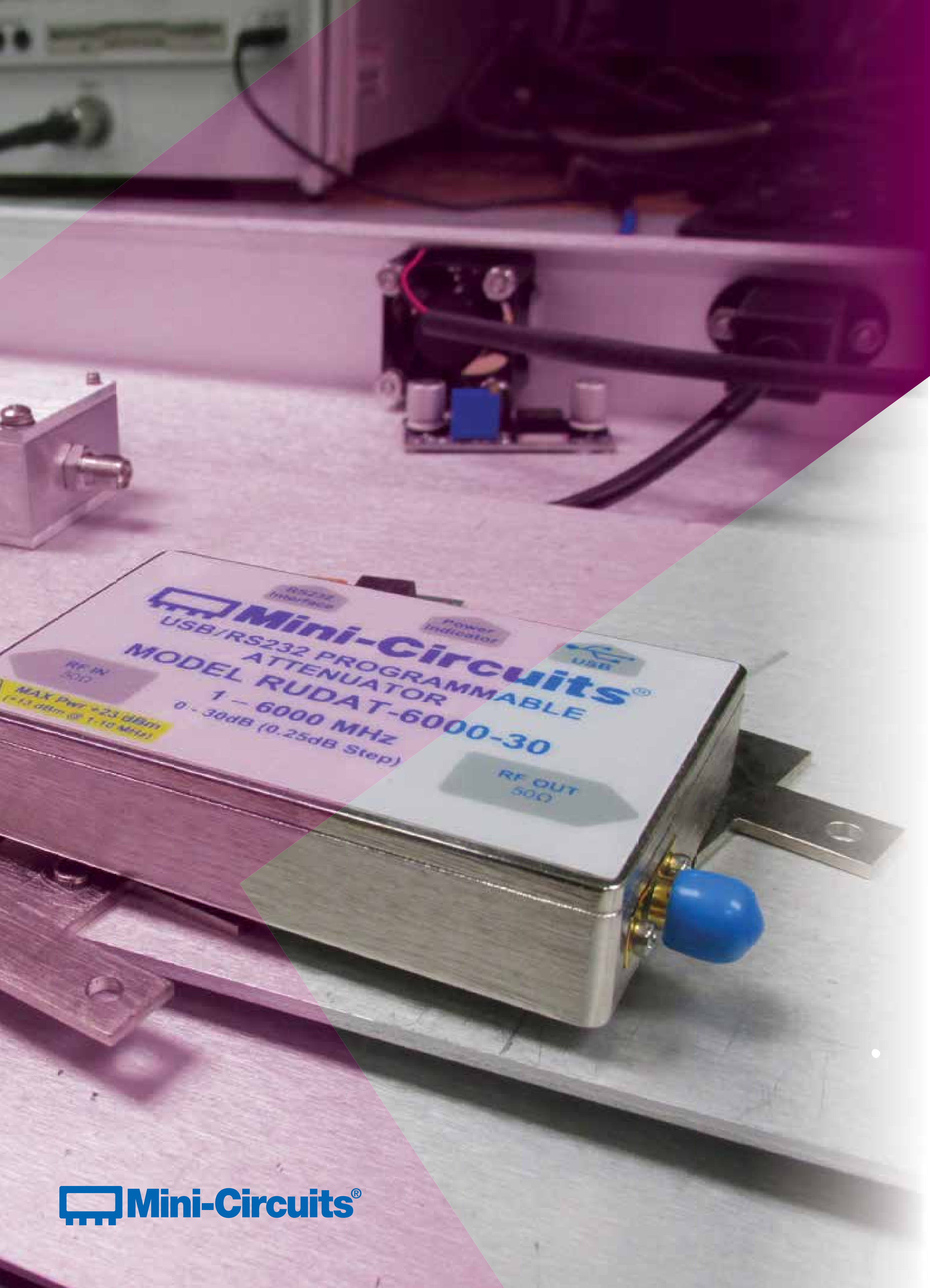

Mini-Circuits®

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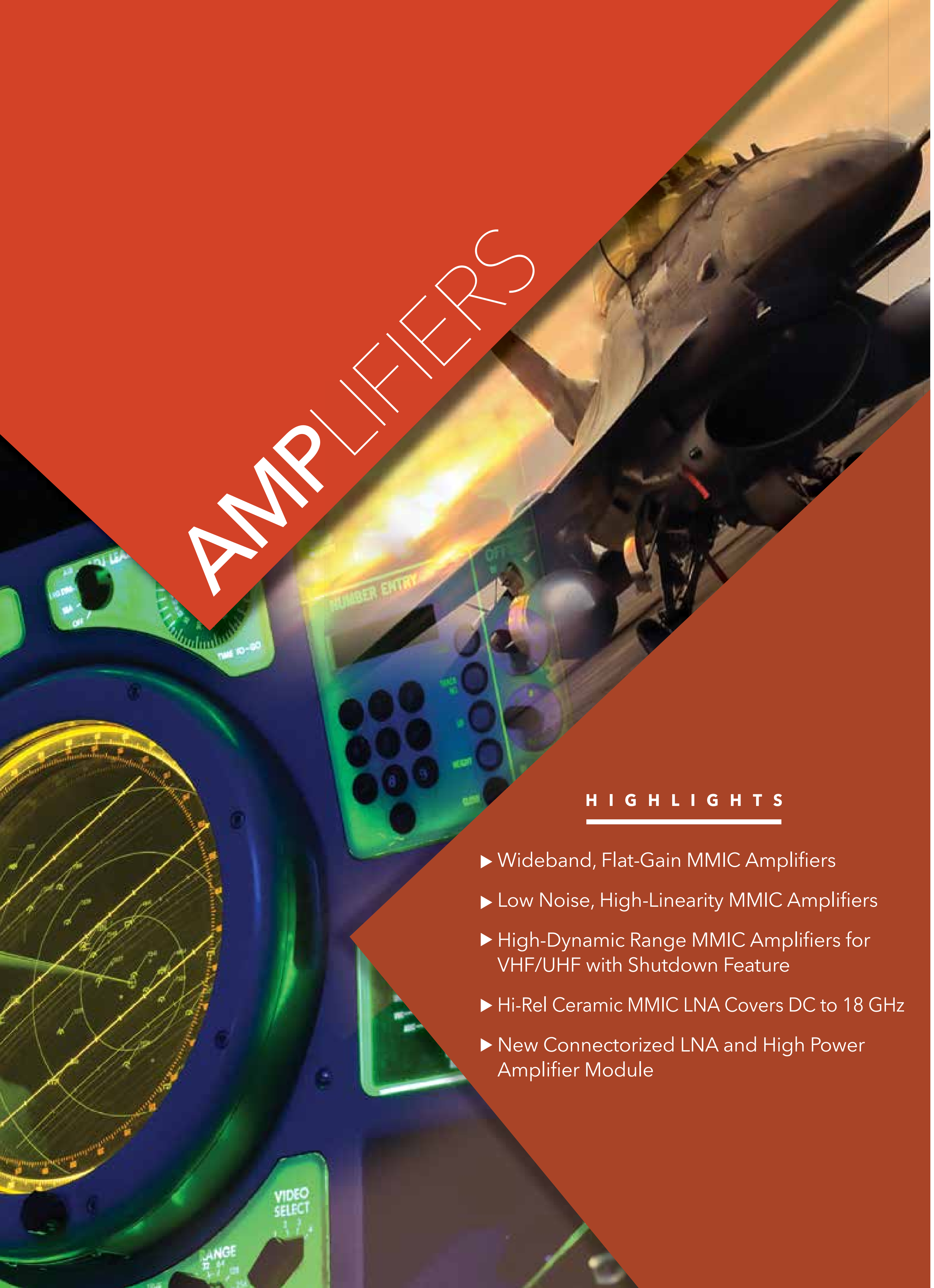
eZ samples Try before you buy

Look inside for specified models!



AMPLIFIERS

HIGHLIGHTS

- ▶ Wideband, Flat-Gain MMIC Amplifiers
- ▶ Low Noise, High-Linearity MMIC Amplifiers
- ▶ High-Dynamic Range MMIC Amplifiers for VHF/UHF with Shutdown Feature
- ▶ Hi-Rel Ceramic MMIC LNA Covers DC to 18 GHz
- ▶ New Connectorized LNA and High Power Amplifier Module

50Ω DC to 12000 MHz

Ultra-Wideband, Flat Gain MMIC Amplifiers

- Outstanding flatness over wide bandwidths
- No external matching required

NEW RELEASE

ez samples Try before you buy Model Number	Frequency Range (MHz)	Gain (dB) Typ.	NF (dB) Typ.	P1dB (dBm) Typ.	OIP3 (dBm) Typ.	Input VSWR (:1) Typ.	Output VSWR (:1) Typ.	Voltage (V)	Current (mA)
GVA-123+	10-12000	16.9	4	16.2	30	1.2	1.2	5	52
GVA-93+	10- 9000	16.9	4	16.2	30	1.2	1.2	5	52
GVA-82+	DC-7000	13.8	6.6	20.6	36	1.3	1.6	5	106
GVA-83+	DC-7000	17.1	6.2	18.6	31.5	1.3	1.8	5	72
GVA-84+	DC-7000	16	5.5	20.6	35.8	1.3	2.6	5	108
GVA-62+	10-6000	15.4	5.1	19.2	33.6	1.5	1.3	5	82
GVA-63+	10-6000	20	3.7	18.6	32.2	1.1	1.35	5	69
GVA-81+	DC-6000	10	7.4	19.7	36.6	1.3	1.3	5	103
GVA-60+	10-5000	19.8	4	19.5	35.6	1.4	1.9	5	92
GVA-91+	869-2170	20.4	6.4	28.8	40	1.8	1.3	5	147
GVA-92+	869-2170	21.2	6	24.1	42	1.8	2	5	99

50Ω 50 to 15000 MHz

Low Noise, High-Dynamic Range MMIC Amplifiers

- Wide bandwidths with flat gain
- Noise figure as low as 0.5 dB
- IP3 up to +40 dBm

NEW RELEASE

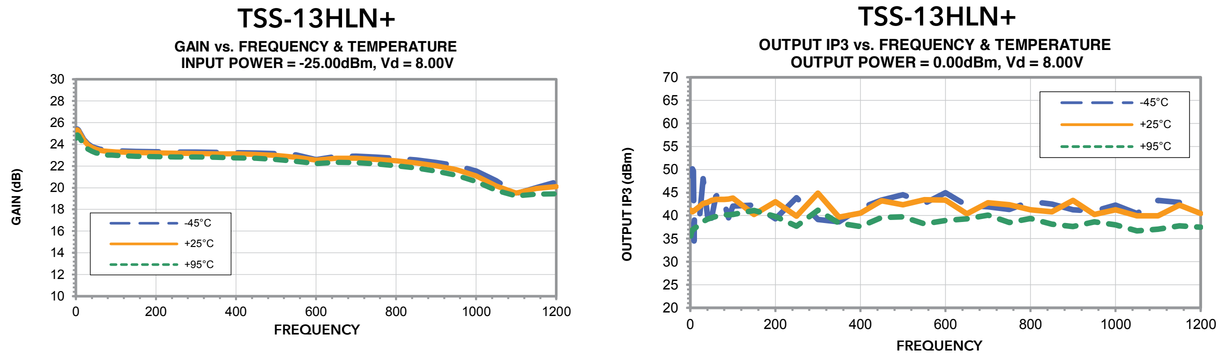
ez samples Try before you buy Model Number	Frequency Range (MHz)	Gain (dB) Typ.	NF (dB) Typ.	P1dB (dBm) Typ.	OIP3 (dBm) Typ.	Input VSWR (:1) Typ.	Output VSWR (:1) Typ.	Voltage (V)	Current (mA)
PMA2-153LN+	500-15000	16.8	2.6	14.8	26.8	1.97	1.15	5.0/6.0	50/66
PMA2-133LN+	10000-13000	15.3	1.3	13.5	28.6	1.24	1.08	3.0/5.0	13/29
PMA2-123LN+	500-12000	16.8	2.6	14.9	27	1.96	1.17	5.0/6.0	51/68
PMA3-83LN+	500-8000	22.1	1.3	20.7	35.2	1.38	1.58	5.0/6.0	60/77
PMA3-63GLN+	1800-6000	27.9	0.7	14.1	26.6	1.78	1.92	5.0	69
PMA-545+	50-6000	14.2	0.8	20.3	36.4	2.3	1.3	3	80
PMA-5451+	50-6000	13.7	0.8	16.8	30.8	2.6	1.3	3	30
PMA-5452+	50-6000	14	0.7	18.3	34.1	2.6	1.3	3	40
PMA-5453+	50-6000	14.3	0.7	19.64	36.8	2.6	1.3	3	60
PMA-5454+	50-6000	13.5	0.9	14.6	28.1	2.9	1.3	5	20
PMA-5455+	50-6000	14	0.8	19.1	32.7	2.6	1.3	5	40
PMA-5456+	50-6000	14.4	0.8	21.5	36	2.6	1.3	5	60
PMA2-43LN+	1100-4000	19.9	0.46	19.9	32.9	1.35	1.64	5	51
PMA3-352GLN+	2500-3500	28.5	0.7	14.8	27.8	1.78	1.92	5.0	69
PMA4-33GLN+	700-3000	38.9	0.47	22.6	40.4	1.6	1.9	5	152
PMA2-33LN+	400-3000	19.1	0.38	17.2	34.5	1.9	1.2	3	56
PMA2-252LN+	1500-2500	17.6	0.8	17.8	30	1.3	1.3	4	57
PMA-545G1+	400-2200	31.3	1	22.2	33.6	1.6	1.4	5	158
PMA-545G2+	1100-1600	30.4	1	22	33.6	1.6	1.4	5	158
PMA2-162LN+	700-1600	22.7	0.5	20	30	1.3	1.3	4	55
PMA-545G3+	700-1000	31.3	0.9	21.9	33.4	1.6	1.4	5	158

50Ω 1 to 2000 MHz

Ultra-High Dynamic Range MMIC Amplifiers with Shutdown Feature

- Extremely wide bandwidths cover VHF/UHF applications
- Noise figure as low as 1.1 dB
- IP3 up to +42.9 dBm
- Internal shutdown feature
- 3.5V and 8V supply options

ez samples Try before you buy Model Number	Frequency Range (MHz)	Gain (dB) Typ.	NF (dB) Typ.	P1dB (dBm) Typ.	OIP3 (dBm) Typ.	Input VSWR (:1) Typ.	Output VSWR (:1) Typ.	Voltage (V)	Current (mA)
ez TSS-13LN+	1-1000	22.8	1.1	24.5	39.2	1.28	1.32	5/3	142/72
ez TSS-13HLN+	1-1000	23	1.4	28.4	42.9	1.43	1.37	8	234
ez TSS-23LN+	30-2000	21.5	1.2	24.1	36.4	1.92	1.67	5/3	139/74
ez TSS-23HLN+	30-2000	21.8	1.4	28.5	42.6	1.92	1.67	8	236

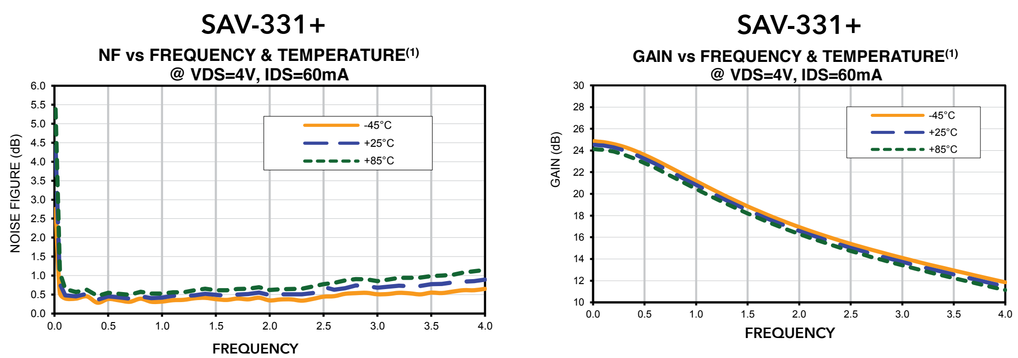


50Ω 10 to 4000 MHz

Ultra-Low Noise D-PHEMT Transistor

- Low noise, 0.5 dB
- High gain, 24.1 dB
- High IP3, +32.3 dBm
- High P1dB, +19.6 dBm
- Low current, 60mA

ez samples Try before you buy Model Number	Frequency Range (MHz)	Gain (dB) Typ.	NF (dB) Typ.	P1dB (dBm) Typ.	OIP3 (dBm) Typ.	Input VSWR (:1) Typ.	Output VSWR (:1) Typ.	Voltage (V)	Current (mA)
ez SAV-331+	10-4000	24.1	0.5	19.6	32.3	-	-	4	60

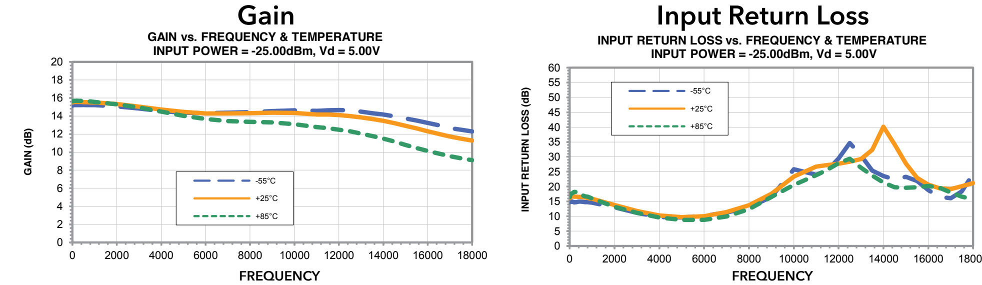


50Ω DC to 18000 MHz

Ultra-Wideband Hi-Rel Ceramic MMIC Amplifiers

- Ceramic, hermetically sealed, nitrogen filled
- Excellent gain flatness, ±2.1 dB
- Low current, 20 mA typ.
- No external matching required

ez samples Try before you buy Model Number	Frequency Range (MHz)	Gain (dB) Typ.	NF (dB) Typ.	P1dB (dBm) Typ.	OIP3 (dBm) Typ.	Input VSWR (:1) Typ.	Output VSWR (:1) Typ.	Voltage (V)	Current (mA)	Package Size
ez CMA-183L+	DC-18000	14.2	5.5	5.4	17.5	-	-	5	20	0402

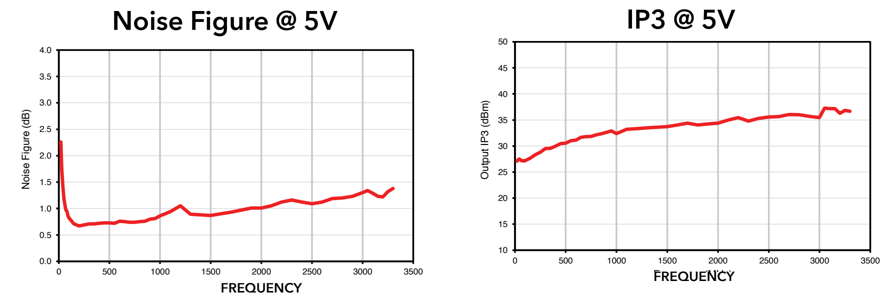


50Ω 50 to 3000MHz

Coaxial Low Noise Amplifier

- Low noise figure, 1.1 dB
- High IP3, +35 dBm
- Rugged unibody constriction with SMA connectors

Model Number	Frequency Range (MHz)	Gain (dB) Typ.	NF (dB) Typ.	P1dB (dBm) Typ.	OIP3 (dBm) Typ.	Input VSWR (:1) Typ.	Output VSWR (:1) Typ.	Voltage (V)	Current (mA)	Connector Type
ZX60-33LNR-S+	50-3000	14.1	1.1	19	35	2	1.6	5	80	SMA

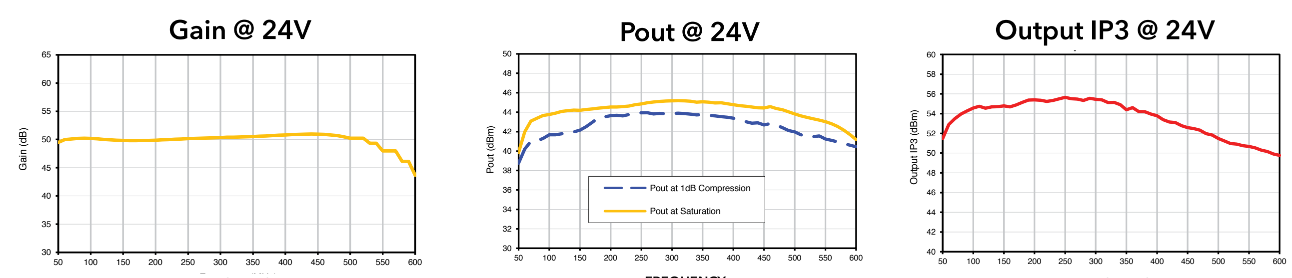


50Ω 70 to 500MHz

20W Class A Amplifier

- Excellent gain flatness, ±0.7 dB
- High output power, 20W
- High gain, 50 dB
- High directivity, 25 dB

Model Number	Frequency Range (MHz)	Gain (dB) Typ.	NF (dB) Typ.	P1dB (dBm) Typ.	OIP3 (dBm) Typ.	Input VSWR (:1) Typ.	Output VSWR (:1) Typ.	Voltage (V)	Current (mA)	Connector Type	Option
ZHL-20W-52-S	70-500	50	7.0	42	53	1.5	2.0	24	4700	SMA	Heat Sink



HIGHLIGHTS

- ▶ Ultra-Wideband MMIC Couplers up to 43.5 GHz
- ▶ High-Power Surface Mount Bi-Directional Couplers up to 150W
- ▶ 75Ω Directional Couplers for DOCSIS® 3.1 Extended Bandwidth up to 1800 GHz
- ▶ Super-Wideband Coaxial Directional Couplers, as wide as 0.5 to 40 GHz in a Single Model

50Ω 0.81-43.5 GHz

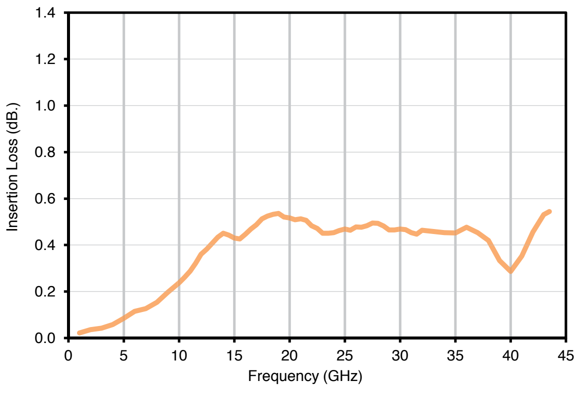
Wideband MMIC couplers

- Multi-octave Bandwidths
- Low mainline loss
- Excellent coupling flatness
- No external termination required
- Highly repeatable performance

NEW RELEASES ez samples Model Number	Frequency Range (GHz)	Coupling	Mainline Loss (dB) Typ.	Directivity (dB) Typ.	VSWR (:1) Typ.	Power Input Max. (W)	Type	Construction	Package
ez D17IA+	2.3-2.6	17.1	0.4	14	1.1	4	Directional	MMIC	3.1 x 3.0 x 1.6mm
ez D17W+	0.7-3.5	16-26	0.4	14	1.25	4	Directional	MMIC	3.1 x 3.0 x 1.6mm
ez D18PA+	1.7-2.0	19.3	0.3	16	1.1	4	Directional	MMIC	3.1 x 3.0 x 1.6mm
ez D19GA+	1.4-1.7	20.7	0.3	17	1.1	4	Directional	MMIC	3.1 x 3.0 x 1.6mm
ez D20C+	0.81-0.96	19.2	0.3	15	1.1	1	Directional	MMIC	3.1 x 3.0 x 1.6mm
EBDC19-KA-D+	5-43.5	18.7	0.6	10	1.45	1.45	Bi-Directional	MMIC	Die
EDC10-183+	6-18	10	1.3	16	1.329	0.63	Directional	MMIC	4x4mm
EDC10-273+	6-26.5	10	1.4	15	1.329	0.63	Directional	MMIC	4x4mm
EDC10-273-D+	6-26.5	10	1.4	15	1.329	0.63	Directional	MMIC	Die
EDC19-KA-D+	5-43.5	18.3	0.5	9.3	1.4	1.47	Directional	MMIC	Die
EDC21-24+	4-20	21	0.7	19	1.37	1.77	Directional	MMIC	4x4mm
EDC21-24-D+	4-20	21	0.7	19	1.37	1.77	Directional	MMIC	Die

EDC19-KA-D+

Insertion Loss



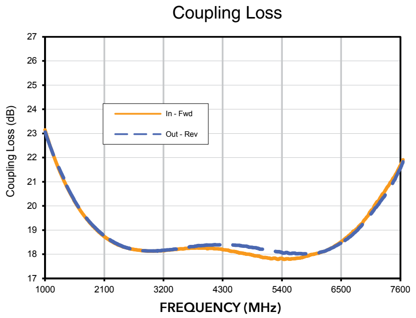
50Ω 800 to 6000 MHz

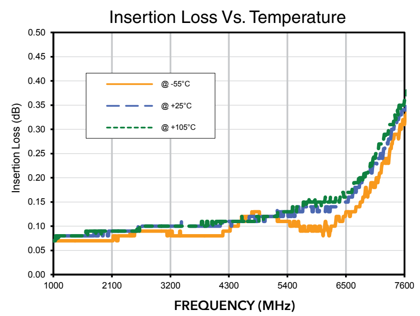
High Power Stripline Bi-Directional Couplers

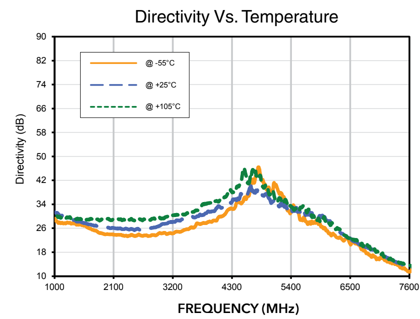
- Very high power in miniature SMT package, up to 150W
- Low mainline loss
- Good directivity, up to 28 dB

Model Number	Frequency Range (MHz)	Coupling (dB) Nom.	Mainline Loss (dB) Typ.	Directivity (dB) Typ.	VSWR (:1) Typ.	Power Input Max. (W)	Type	Construction
BDCH-20-63A+	2000 - 6000	18	0.15	29	1.1	140	Bi-Directional	Microstrip / Stripline
BDCH-25-33+	800 - 3000	25	0.2	28	1.2	150	Bi-Directional	Microstrip / Stripline

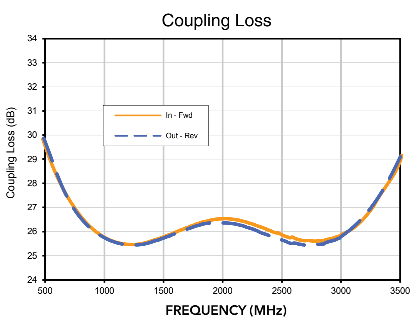
BDCH-20-63A+

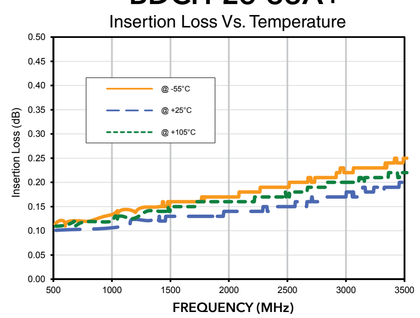


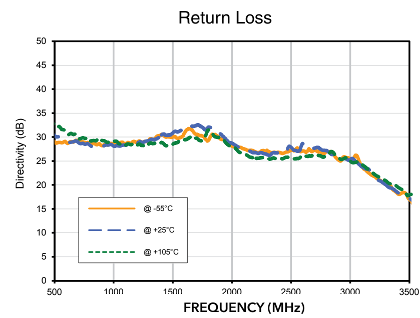




BDCH-25-33A+



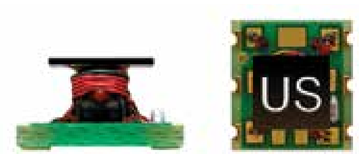




75Ω 5 to 1800 MHz

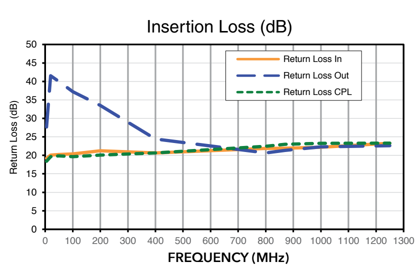
Wideband Directional Couplers for DOCSIS® 3.1

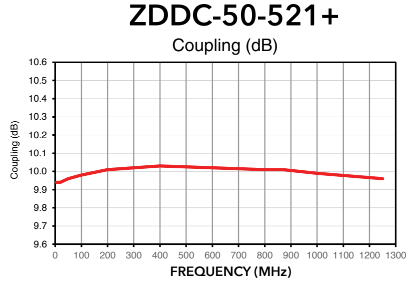
- Supports DOCSIS 3.1 extended bandwidth
- 10 dB coupling with excellent flatness across the full band

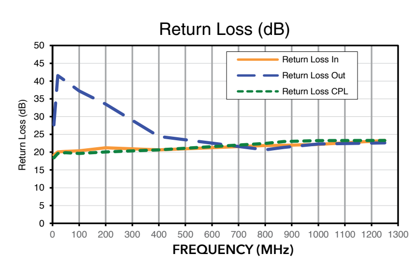


ez samples Try before you buy Model Number	Frequency Range (MHz)	Coupling (dB) Nom.	Mainline Loss (dB) Typ.	Directivity (dB) Typ.	VSWR (:1) Typ.	Power Input Max. (W)	Type	Construction
ez RDC-10-182-75X+	5 - 1800	10	1.3	20	1.2	1	Directional	Transformer

ZDDC-50-521+



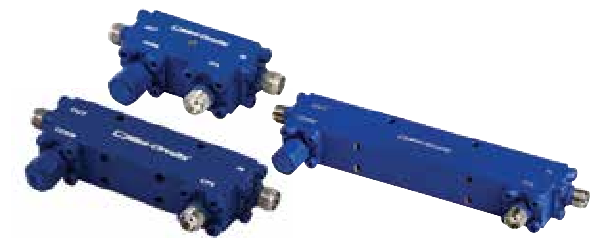




50Ω 0.5 to 40 GHz

Super-Wideband Coaxial Directional Couplers

- Industry leading bandwidth, 0.5 to 40 GHz in a single model!
- Excellent directivity



LATEST RELEASES Model Number	Frequency Range (MHz)	Coupling (dB) Nom.	Mainline Loss (dB) Typ.	Directivity (dB) Typ.	VSWR (:1) Typ.	Power Input Max. (W)	Type	Construction
ZCDC10-5R263-S+	500 - 26500	10	1.2	22	1.12	20	Directional	Microstrip / Stripline
ZCDC10-01263-S+	1000 - 26500	10	0.9	21	1.17	20	Directional	Microstrip / Stripline
ZCDC10-02263S+	2000 - 26500	10	0.9	27	1.11	20	Directional	Microstrip / Stripline
ZCDC10-06263-S+	6000 - 26500	10	1.0	22	1.17	20	Directional	Microstrip / Stripline
ZCDC10-18263-S+	18000 - 26500	10	0.9	24	1.15	20	Directional	Microstrip / Stripline
ZCDC10-K5R44W+	500 - 40000	10	1.3	23	1.12	15	Directional	Microstrip / Stripline
ZCDC10-K0144+	1000 - 40000	10	2.2	16	1.22	19	Directional	Microstrip / Stripline
ZCDC10-K0244+	2000 - 40000	10	1.2	23	1.11	15	Directional	Microstrip / Stripline
ZCDC10-K0644+	6000 - 40000	10	1.0	24	1.12	17	Directional	Microstrip / Stripline
ZCDC10-K1844+	18000 - 40000	10	1.2	21	1.22	17	Directional	Microstrip / Stripline
ZCDC13-5R263-S+	500 - 26500	13	1.3	21	1.73	20	Directional	Microstrip / Striplin
ZCDC13-01263-S+	1000 - 26500	13	1.2	21	1.17	19	Directional	Microstrip / Stripline
ZCDC13-K0144+	1000 - 40000	13	1.5	19	1.73	13	Directional	Microstrip / Stripline
ZCDC13-K0244+	2000 - 40000	13	0.95	24	1.11	20	Directional	Microstrip / Stripline
ZCDC13-K1844+	18000 - 40000	13	0.9	21	1.13	20	Directional	Microstrip / Stripline
ZCDC13-K26344+	26500 - 40000	13	0.9	21	1.22	20	Directional	Microstrip / Stripline
ZCDC16-5R263-S+	500 - 26500	16	1.4	23	1.12	20	Directional	Microstrip / Stripline
ZCDC16-01263-S+	1000 - 26500	16	0.9	21	1.14	20	Directional	Microstrip / Stripline
ZCDC16-K0144+	1000 - 40000	16	1.3	20	1.22	19	Directional	Microstrip / Stripline
ZCDC16-K1844+	18000 - 40000	16	0.7	23	1.10	20	Directional	Microstrip / Stripline
ZCDC20-5R263-S+	500 - 26500	20	0.9	25	1.09	20	Directional	Microstrip / Stripline
ZCDC20-01263-S+	1000 - 26500	20	0.9	23	1.12	20	Directional	Microstrip / Stripline
ZCDC20-02263S+	2000 - 26500	20	0.5	18	1.33	20	Directional	Microstrip / Stripline
ZCDC20-06263-S+	6000 - 26500	20	0.5	26	1.14	20	Directional	Microstrip / Stripline
ZCDC20-18263-S+	18000 - 26500	20	0.4	24	1.14	20	Directional	Microstrip / Stripline
ZCDC20-K0144+	1000 - 40000	20	1.2	20	1.20	20	Directional	Microstrip / Stripline
ZCDC20-K0244+	2000 - 40000	20	1.0	20	1.17	20	Directional	Microstrip / Stripline
ZCDC20-K0644+	6000 - 40000	20	0.7	22	1.07	20	Directional	Microstrip / Stripline
ZCDC20-K1844+	18000 - 40000	20	0.7	19	1.17	20	Directional	Microstrip / Stripline
ZCDC30-5R263-S+	500 - 26500	30	0.6	28	1.07	20	Directional	Microstrip / Stripline
ZCDC30-01263-S+	1000 - 26500	30	0.8	23	1.14	20	Directional	Microstrip / Stripline
ZCDC30-02263-S+	2000 - 26500	30	0.6	23	1.14	20	Directional	Microstrip / Stripline
ZCDC30-06263-S+	6000 - 26500	30	0.6	23	1.12	20	Directional	Microstrip / Stripline
ZCDC30-18263-S+	18000 - 26500	30	0.6	21	1.14	20	Directional	Microstrip / Stripline
ZCDC30-K0644+	6000 - 40000	30	0.5	22	1.12	20	Directional	Microstrip / Stripline
ZCDC30-K1844+	18000 - 40000	30	0.6	22	1.15	20	Directional	Microstrip / Stripline

HIGHLIGHTS

- Expanded selection of our popular MMIC fixed gain slope equalizers now includes models with ultra-wide frequency range from DC to 20 GHz!

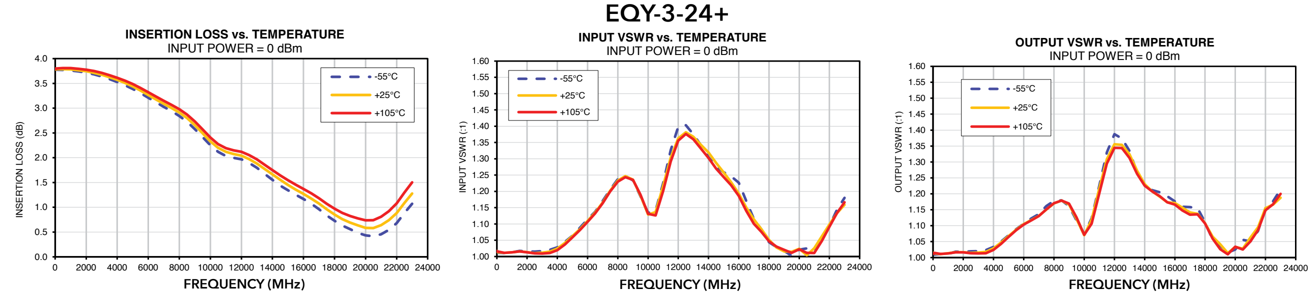
50Ω DC to 20 GHz

Ultra-Wideband MMIC Fixed Equalizers

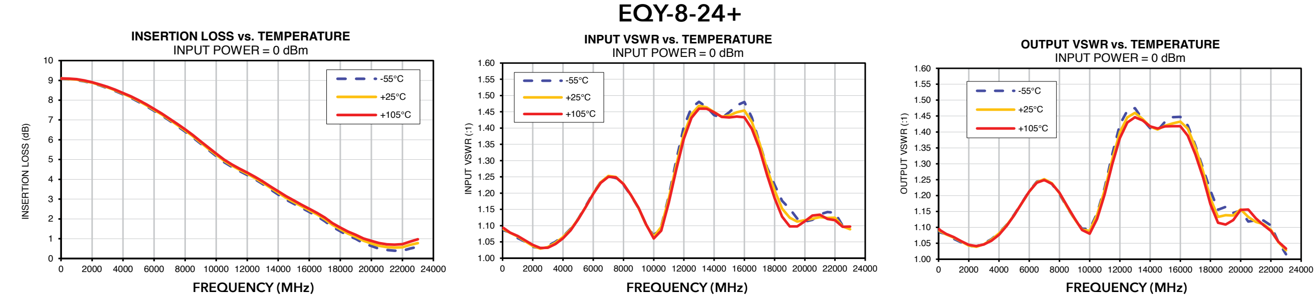
- Now 6 GHz and 20 GHz Versions
- Excellent return loss, 20 dB typ.
- 2x2mm QFN and bare die

NEW RELEASES ezsamples Model Number	Package	Frequency Range (GHz)	Impedance (Ω)	Insertion Loss (dB) @ Freq. Range	VSWR (:1) Typ. Input	VSWR (:1) Typ. Output	Max Input Power (dBm)
EQY-1-63+ EQY-1-63-D+	2x2mm QFN Die	DC-6	50	1.6-0.4	1.24	1.24	31
EQY-2-24+	2x2mm QFN	DC-20	50	3.0-0.9	1.16	1.16	31
EQY-2-63+ EQY-2-63-D+	2x2mm QFN Die	DC-6	50	2.5-0.4	1.29	1.29	31
EQY-3-24+ EQY-3-24-D+	2x2mm QFN Die	DC-20	50	3.8-0.7	1.15	1.15	34
EQY-3-63+ EQY-3-63-D+	2x2mm QFN Die	DC-6	50	3.8-0.6	1.29	1.29	31
EQY-4-63+ EQY-4-63+	2x2mm QFN Die	DC-6	50	4.8-0.6	1.25	1.25	31
EQY-5-24+	2x2mm QFN	DC-20	50	5.8-0.7	1.24	1.24	34
EQY-5-63+ EQY-5-63-D+	2x2mm QFN Die	DC-6	50	6-1	1.24	1.24	31
EQY-6-24+ EQY-6-24-D+	2x2mm QFN Die	DC-20	50	6.8-0.5 6.8-0.7	1.22 1.30	1.22 1.30	31
EQY-6-63+ EQY-6-63-D+	2x2mm QFN Die	DC-6	50	7-0.5	1.2	1.2	32
EQY-8-24+ EQY-8-24-D+	2x2mm QFN Die	DC-20	50	9.1-0.8 9.1-1.1	1.18 1.31	1.18 1.31	34
EQY-8-63+ EQY-8-63-D+	2x2mm QFN Die	DC-6	50	8.7-0.5	1.21	1.21	31
EQY-10-24+ EQY-10-24-D+	2x2mm QFN Die	DC-20	50	11.1-0.9 11.1-1.1	1.18 1.28	1.18 1.28	33
EQY-10-63+ EQY-10-63-D+	2x2mm QFN Die	DC-6	50	11.2-1	1.12	1.12	31
EQY-12-24+ EQY-12-24-D+	2x2mm QFN Die	DC-20	50	13.4-1.4 13.4-1.5	1.09 1.17	1.09 1.17	30

EQY-3-24+



EQY-8-24+



FILTERS & DIPLEXERS

HIGHLIGHTS

- New Line of Waveguide Bandpass Filters for Millimeter Wave Applications up to 86 GHz!
- New high-Q surface mount ceramic resonator bandpass filters
- Suspended substrate diplexers with ultra-wide bassbands
- LTCC Low pass filters with enhanced rejection and reduced size

Mini-Circuits® | VDI Virginia Diodes, Inc.

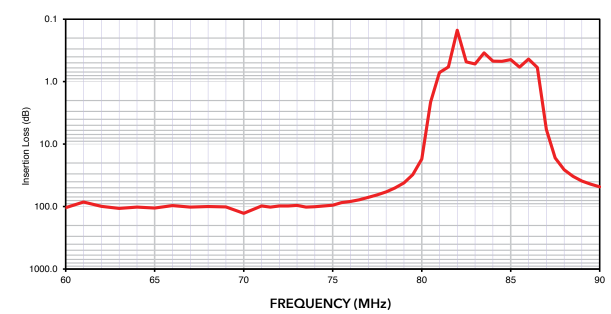
Frequency Bands from: 27 to 86 GHz

Waveguide Bandpass Filters

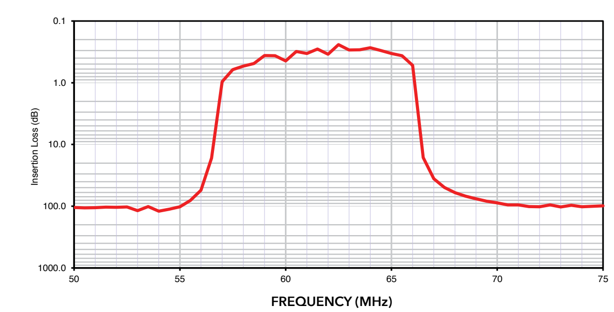
- Precision machining and plating
- Outstanding return loss
- Super-high rejection and fast roll off
- Standard WR-12 to WR-28 waveguide interfaces

Model Number	Passband (GHz)	Stopband F3 (MHz)	Rejection @ F3 (dB)	Stopband F4 (MHz)	Rejection @ F4 (dB)	Flter Type	Technology
WVBP-283-WR28+	27.5 - 28.35	22000-27000	48	28850-38000	34	Band Pass	Rectangular Waveguide
WVBP-383-WR28+	37 - 40	22000-36000	59	41000-42000	34	Band Pass	Rectangular Waveguide
WVBP-613-WR15+	57.2 - 65.9	50000-56200	74	66900-75000	65	Band Pass	Rectangular Waveguide
WVBP-673-WR12+	64 - 71	60000-61500	56	73500-90000	28	Band Pass	Rectangular Waveguide
WVBP-733-WR12+	71 - 76	60000-69500	56	77500-90000	66	Band Pass	Rectangular Waveguide
WVBP-783-WR12+	76 - 81	60000-74500	67	82500-90000	48	Band Pass	Rectangular Waveguide
WVBP-833-WR12+	81 - 86	60000-79000	64	88000-90000	38	Band Pass	Rectangular Waveguide

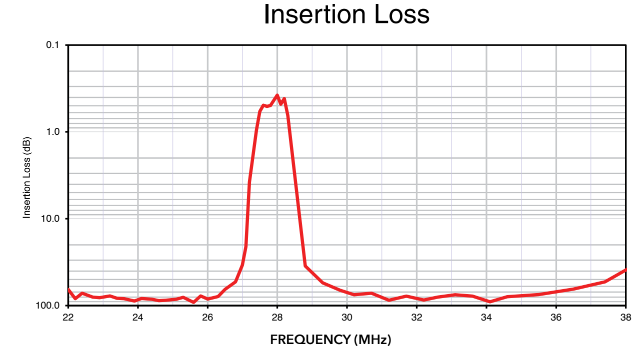
WVBP-833-WR12+
Insertion Loss



WVBP-613-WR15+
Insertion Loss



WVBP-283-WR28+
Insertion Loss



50Ω 800 to 6000 MHz

Ceramic Resonator Bandpass Filters

- Low insertion loss with excellent power handling
- Fractional bandwidth from 3% to 25%
- Low profile designs with min. height of 0.120″
- Excellent temperature stability
- Rugged construction to handle demanding environmental conditions

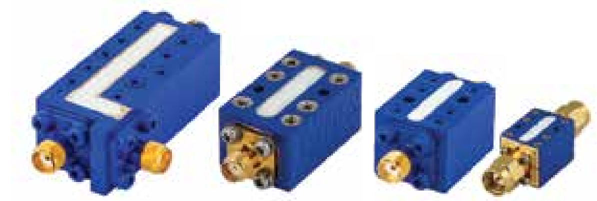
LATEST RELEASES Model Number	Passband F1 (MHz)	Passband F2 (MHz)	Stopband F3 (MHz)	Rejection @ F3 (dB)	Stopband F4 (MHz)	Rejection @ F4 (dB)	Filter Type
CBP-1413R5A+	1400	1427	1300-1350	20	1475-1520	20	Band Pass
CBP-5800AG+	5725	5825	DC-5100	20	6250-7300	20	Band Pass
CBP-1060Q+	1030	1090	500-930	20	1190-1400	20	Band Pass
CBP-1320Q+	1280	1360	900-1170	20	1490-20000	20	Band Pass
CBP-2250A+	2000	2500	DC-1630	20	2900-6000	35	Band Pass
ZX75BP-4700-S+	4400	5000	DC-2800	40	6300-8000	30	Band Pass

CBP-5800AG+

50Ω DC-26 GHz, 40000-20000 MHz

Suspended Substrate Filters and Diplexers

- Low insertion loss
- Ultra-wide passband width
- Fast roll-off with wide stopband
- Passband up to 26 GHz
- Stopband up to 26.5 GHz can extend to 40 GHz



Diplexers

NEW RELEASE Model Number	Passband (MHz)	Passband IL (MHz)	Rejection (dB)	Return Loss (dB)	Crossover Isolation (dB)	Filter Type	Technology
ZDSS-3G4G-S+	DC-3000 4000-20000	1.5	30 @ 4000-20000 15 @ DC-3000	10	-	Diplexer	Suspended Substrate
ZDSS-5G6G-S+	DC-5000 6000-20000	1.5	80 @ 7200-20000 50 @ DC-4000	10 8	-	Diplexer	Suspended Substrate

Band Pass

Model Number	Passband F1 (MHz)	Passband F2 (MHz)	Stopband F3 (MHz)	Rejection @ F3 (dB)	Stopband F4 (MHz)	Rejection @ F4 (dB)	Filter Type	Technology
ZBSS-7975-S+	7825	8125	DC-6900	35	9350-15000	35	Band Pass	Suspend Substrate

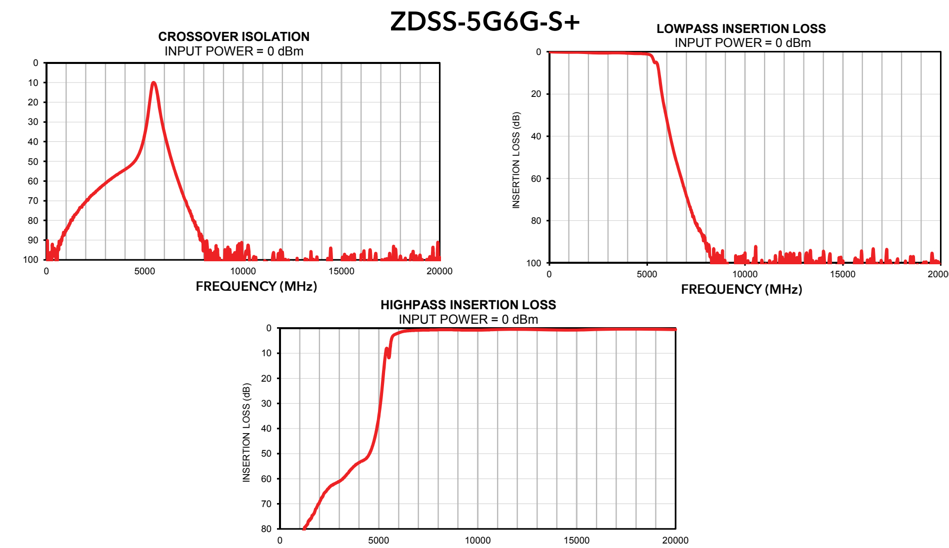
Low Pass

Model Number	Passband F1 (MHz)	Passband F2 (MHz)	Stopband F3 (MHz)	Rejection @ F3 (dB)	Stopband F4 (MHz)	Rejection @ F4 (dB)	Filter Type	Technology
ZLSS-2R8G-S+	2800	3300	4000-4700	20	4700-26500	40	Low Pass	Suspended Substrate
ZLSS-4G-S+	4000	4500	5500-6300	20	6300-26500	40	Low Pass	Suspended Substrate
ZLSS-6G-S+	6000	6600	8200-9600	20	9600-26500	40	Low Pass	Suspended Substrate
ZLSS-8G-S+	8000	8600	10800-12500	20	12500-26500	40	Low Pass	Suspended Substrate
ZLSS-11G-S+	11000	11400	12500-14500	20	14500-26500	40	Low Pass	Suspended Substrate
ZLSS-14G-S+	14000	15100	16500-18000	20	18000-26500	40	Low Pass	Suspended Substrate

High Pass

Model Number	Passband F1 (MHz)	Passband F2 (MHz)	Stopband F3 (MHz)	Rejection @ F3 (dB)	Stopband F4 (MHz)	Rejection @ F4 (dB)	Filter Type	Technology
ZHSS-8G+	8000-24000	-	5300-5800	20	DC-5300	40	High Pass	Suspended S ubstrate

ZDSS-5G6G-S+



50Ω DC to 2850 MHz

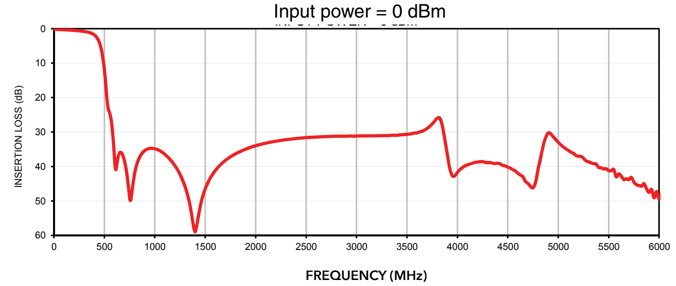
LTCC Low Pass Filters with Enhanced Rejection

- Excellent rejection, up to 33 dB
- Rugged, ceramic construction
- Excellent power handling, up to 5W
- ***Tiny size, 0.079 x 0 .049 x 0.037" (2.0 x 1.25 mm)***

ez samples Model Number	Passband F1 (MHz)	Passband F2 (MHz)	Stopband F3 (MHz)	Rejection @ F3 (dB)	Stopband F4 (MHz)	Rejection @ F4 (dB)	Package size
ez LFCG-42+	DC-435	475	625	20	650-2700	30	0805
ez LFCG-92+	DC -990	1400	1700	20	1800-2700	30	0805
ez LFCG-320+	DC-320	440	660-2000	33	2000-6000	20	0805
ez LFCG-400+	DC-400	520	800-2500	30	2500-4500	20	0805
ez LFCG-530+	DC-530	670	980-2600	30	2600-4000	25	0805
ez LFCG-575+	DC-575	725	1020-2500	30	2500-4400	25	0805
ez LFCG-1000+	DC-1000	1370	1550-1900	20	1900-6000	30	0805
ez LFCG-1575+	DC-1575	1850	2175-2400	20	2400-7000	40	0805
ez LFCG-1700+	DC-1700	2025	2400-2800	20	2800-8000	30	0805
ez LFCG-2250+	DC-2250	2500	2800-3600	20	3600-8000	30	0805
ez LFCG-2850+	DC-2850	3250	3800-4400	20	4400-12000	30	0805

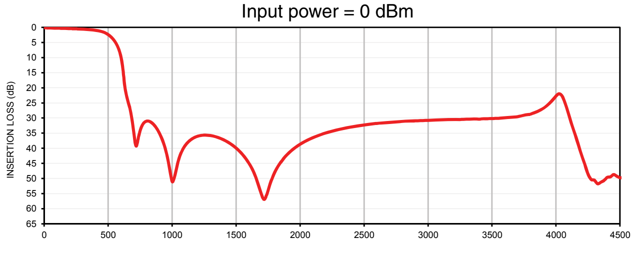
LFCG-320+

Insertion Loss
Input power = 0 dBm



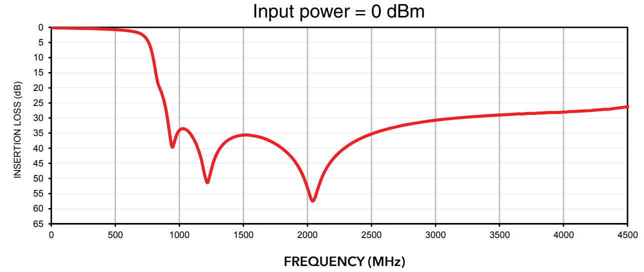
LFCG-400+

Insertion Loss
Input power = 0 dBm



LFCG-575+

Insertion Loss
Input power = 0 dBm



FILTERS

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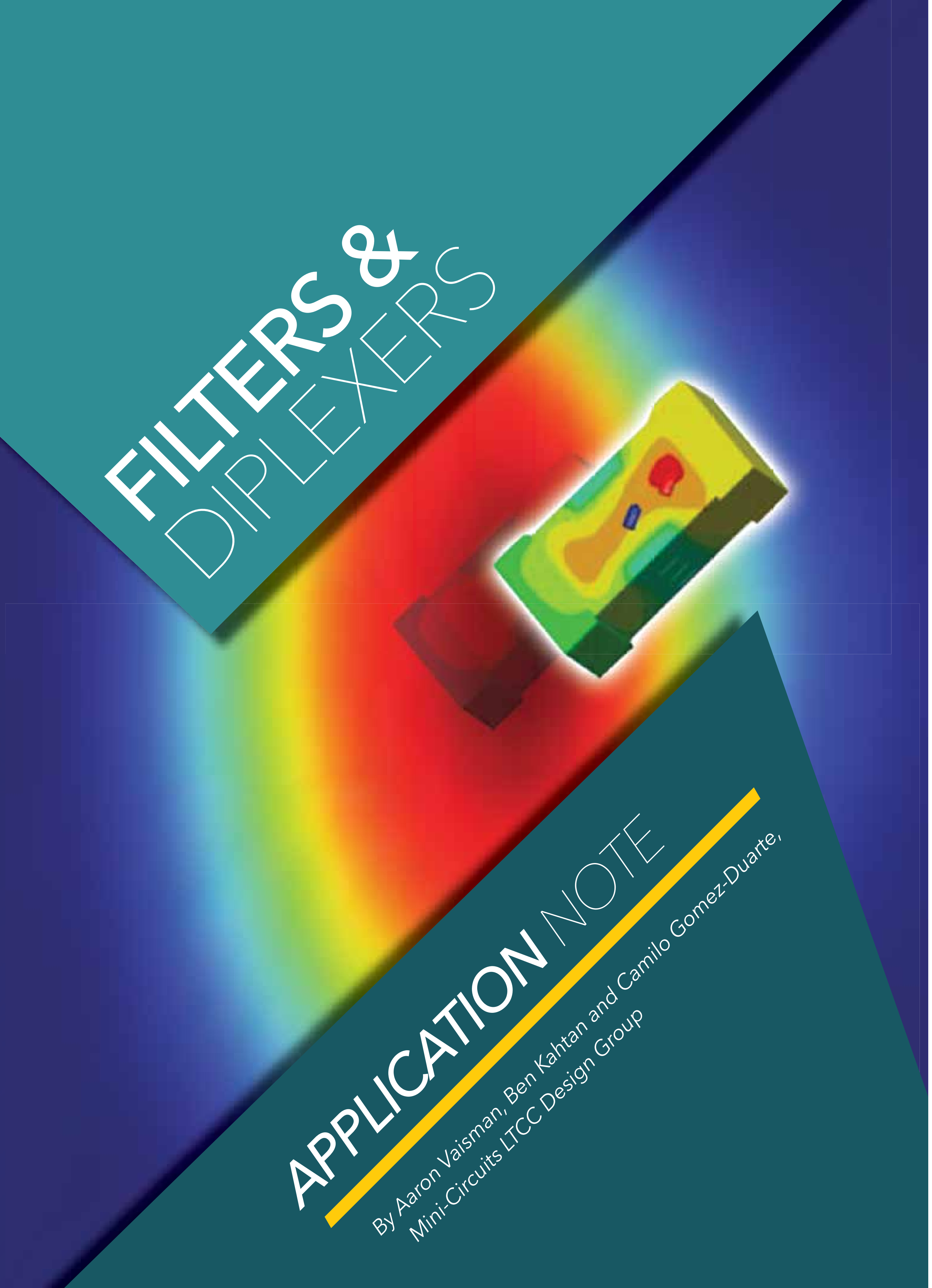


Achieving First-Spin Success in LTCC Components with Advanced Material Simulation Models

Introduction

Since the advent of Network Synthesis Theory at the turn of the last century, filter designers have been developing ever more sophisticated solutions to translate polynomial transfer functions into working, physical components. The body of knowledge for lumped components is well established in the famous "Big Red Filter Bible," *Microwave Filters, Impedance Matching Networks, and Coupling Structures,* by Matthaei, Young and Jones, and for distributed components in James Hong's *Microwave Filters for RF/Microwave Applications.* This knowledge combined with the advent of advanced software tools for filter synthesis and the commercialization of computerized full field solution algorithms such as the Method of Moments (MoM) and the Finite Element Method (FEM) have given designers a powerful toolkit to realize both known and arbitrary topologies.

Even given the maturity of the theory and state of the art in filter synthesis and simulation software, simulation results are still generally taken with a measure of caution. One of the most significant design challenges remains achieving agreement between simulation and working design in a timely fashion. Depending on the technology being used, it's not unusual for designers to cycle through multiple design and manufacturing spins before results meet the desired performance. This adds substantial time and cost to the design cycle, and directly affects time to revenue. Setting up a truly accurate simulation requires capturing every physical parameter that may affect real-world filter performance. Designers need to consider a daunting variety of factors. Some questions that must be considered include:

- *Has the simulation model been parameterized such that the real world variables related to the physical implementation and operating conditions are accounted for?*
- *What kind of interpolation should be used between frequency points?*
- *Does the 3D model capture the physical manifestation of a given structure?*
- *Is the meshing different at different frequency bands?*
- *Is skin depth accounted for correctly within the simulation tool for lower frequency bands?*
- *Is the substrate dispersive, and if so what are its dispersion curves?*
- *Have effective conductivity and the conductor's surface roughness models been accounted for?*

Mini-Circuits LTCC design group has spent years addressing these questions and many others. The reality of traditional simulations is that in the past, material impacts have not been well enough understood to account for all the real-world effects on performance. Therefore, a deeper understanding was necessary to eliminate superfluous manufacturing spins and meet performance requirements on the first try. By combining hundreds of different test structures, extensive material characterization and modelling, novel design workflows and home-brewed algorithms, Mini-Circuits has been able to transfer the trial and error from production runs at the fab to the simulation phase, early in the design process. These innovations have enabled us to consistently achieve first-spin success on LTCC filters and other components beyond 50 GHz.

This article will explore some of the specific challenges of simulating LTCC structures. The design workflow will be described and case studies provided to demonstrate first-spin fidelity between simulation and measurement. Finally, extensions will be discussed for other exploratory filter topologies at high frequencies as well as for other products and technologies.

Material Characterization and Modelling

Mini-Circuits typically combines two common simulation techniques to predict the RF performance of passive devices prior to their fabrication, each with its own pros and cons. The Method of Moments (MoM) technique works by meshing the conductive metallizations within the structure. This method is fast to perform and iterate and is useful for structures with low port count and low ratio of metallization to substrate. However, it is mostly limited to 2D surfaces and assumes substrates extend infinitely in space, so it doesn't provide a true substrate truncated 3D model.

The Finite Element Method (FEM) of simulation provides a true 3D model that allows us to truncate volumes. This is a frequency based method that works by meshing the substrate structures rather than the conductors. FEM simulations better capture the coupling and parasitic effects through the substrate as well as the effects of truncating the 3D structure, which are absent in MoM. The drawback is that FEM simulations are typically slower to implement.

The FEM approach is more accurate for LTCC filters where the signal travels in a 3D fashion through a monolithic structure. Ideally, the characteristics of that structure would be uniform. However, in reality, LTCC structures consist of multiple layers of ceramic and conductive material with dispersive and anisotropic behavior. A true 3D characterization of the material is therefore required to account for the non-linear behavior of signals traveling through a structure with these properties.

While these two approaches are powerful, in the past, they were incapable by themselves of achieving close agreement between simulation and measurement, and multiple design spins were still required. This limitation necessitated a deeper understanding of the material structure for its contributions to the real-world performance of the device. Mini-Circuits has gone through the painstaking effort of characterizing the material properties of substrates and conductive elements used in LTCC products up to the millimeter wave range. This required the use of hundreds of test structures, including single- and multi-modal resonator topologies, waveguide resonators, lumped capacitor and inductor structures, among others. A proprietary algorithm was developed just to analyze the volume of test data from our measurement workflow.

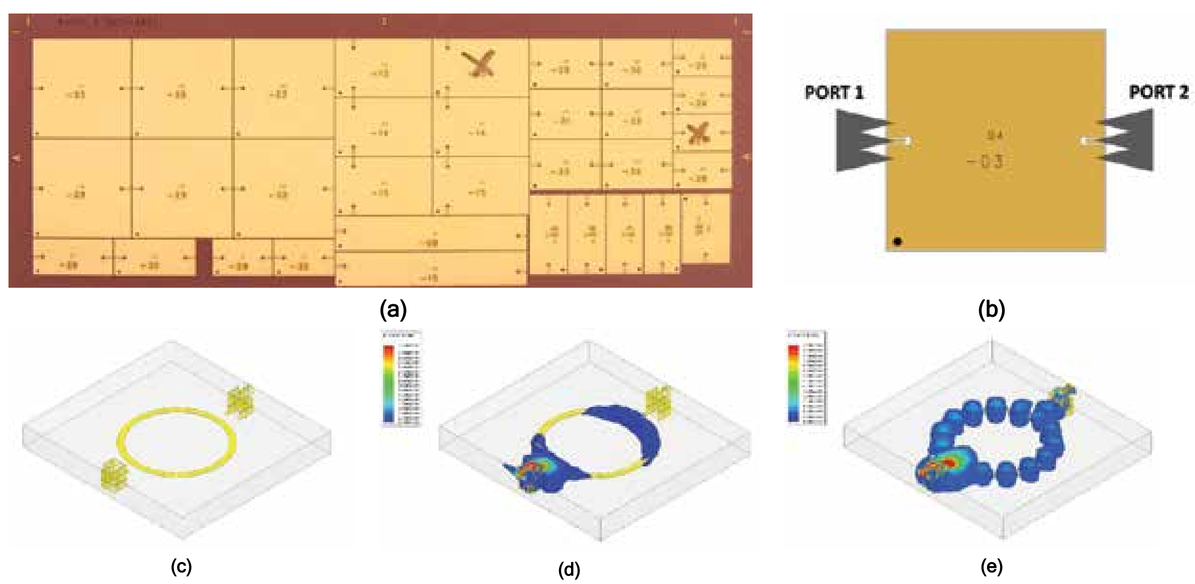


Figure 1: (a) LTCC panel with test coupons. (b) Diagram of measurement setup with RF probes. (c) 3D model of ring resonator (top and bottom layers hidden). (d) Ring resonator: E-Field plot of 1st harmonic. (e) Ring resonator: E-Field plot of 7th harmonic.

After two years of intensive effort building and characterizing test coupons and then modelling the measured performance into our simulation tools across broad bandwidths, Mini-Circuits has amassed what we believe is one of the most advanced understandings of LTCC technology in the industry. Our efforts have included characterization and modelling of the material properties of all elements used not only in our LTCC product line, but also in semiconductor products and other technologies as well. We now have high confidence in our material models which, combined with our suite of design tools and novel design flow, has enabled us to achieve first spin success on component designs up to 50 GHz.

This capability is unique in the industry. It enables Mini-Circuits to develop and release standard parts to our catalog at a faster rate, which supports the needs of customers with high volume requirements, and it enables us to develop highly customized solutions for customers in more specialized applications with very fast turnaround. In all cases, it translates to lower development time and cost, and faster time to market.

Multi-Physics Workflow

Our comprehensive material modelling combined with state-of-the-art design and simulation tools has allowed us to innovate a novel, multi-physics simulation workflow. A multi-physics simulation incorporates multiple simulators, each working within a particular domain: electromagnetic, structural and thermal. The individual simulators use each other's results as a component of their own simulation setups. For example, electrical simulation results from HFSS® are employed to define spatially-varying heat generation in a thermal simulation in ANSYS®. The computed temperature rise is then employed in turn to compute deformation of the model geometry.

This initial simulation series often results in performance that does not meet the specified design requirements, so the effects of thermal and mechanical analysis are fed back into the MoM and FEM engines to compensate for the effects of the thermal impact. This iterative process is completed as many times as necessary to achieve the desired performance. In a traditional design cycle, a prototype would be fabricated after the first round of simulations, tested in the lab, and then redesigned and fabricated again. Our workflow moves that trial and error to the front of the design cycle, avoiding multiple rounds of fabrication and testing in the lab.

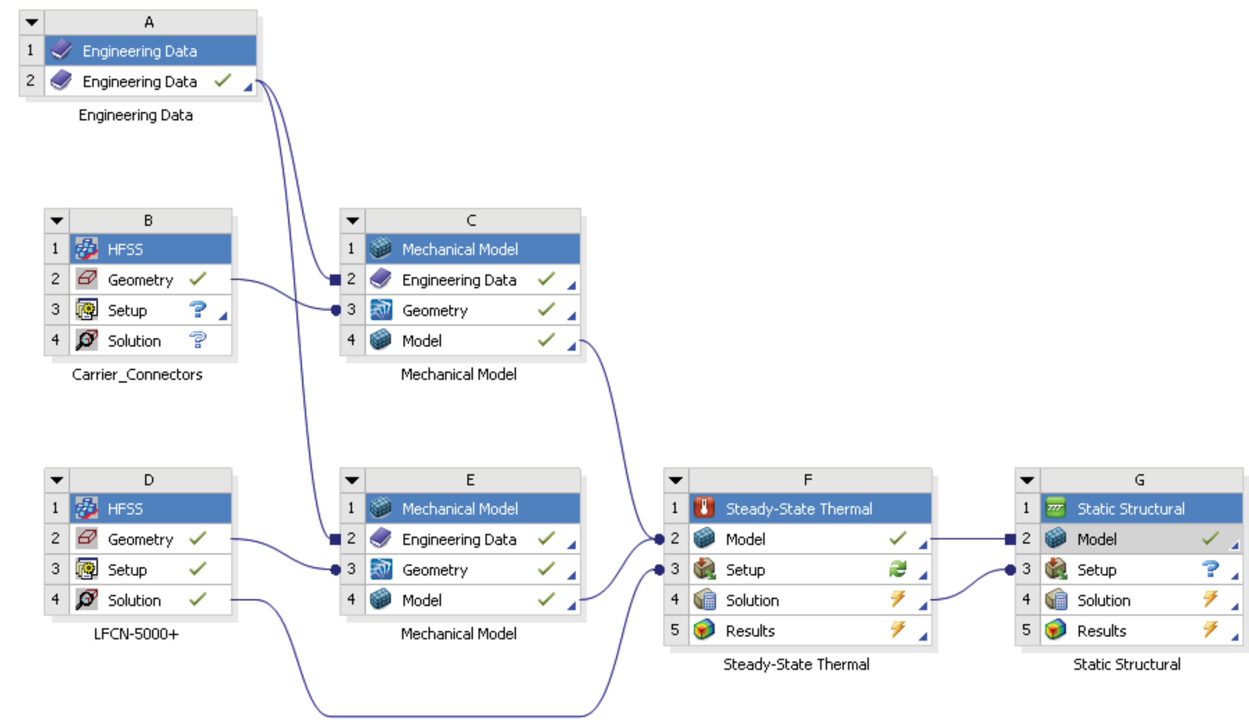


Figure 2: Multi-physics workflow incorporating electromagnetic, thermal and structural simulations

Consider for example a customer requirement for a part that can handle 4W RF input power. Traditionally, the part would be designed and an evaluation run fabricated. The parts would be soldered to eval boards and put through burn-in test. If the part then burns out at 3W, it would need to be redesigned. Because LTCC products are monolithic, it isn't practical to find the point of failure through destructive physical analysis. By contrast, with a multi-physics simulation workflow, we are able to accurately and reliably evaluate power handling prior to the first build of the device, saving time, cost, and no small measure of frustration.

Advantages of this workflow include:

- Greater insight into the power handling of a model under diverse operating conditions (DC, RF and transient)
- Realistic assessment and optimization of thermal impact on RF performance and reliability
- Forecasting of mechanical integrity of terminals in the presence of CTE mismatches
- Optimization of the physical structures to reduce size

FILTERS

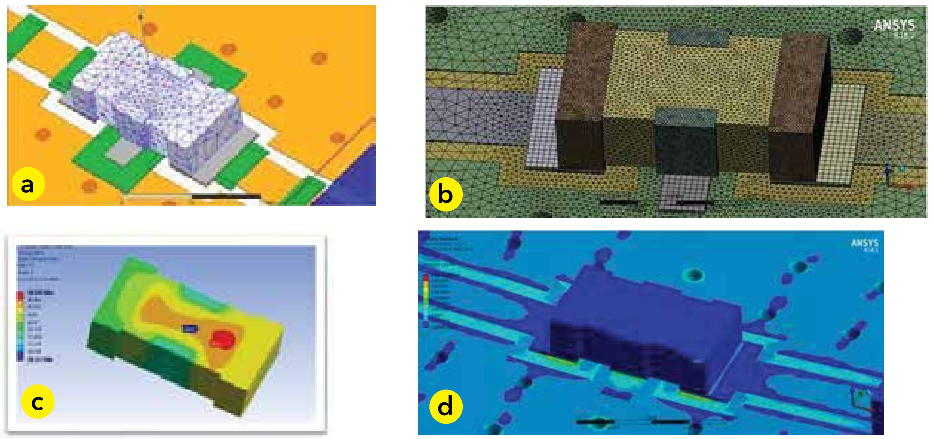


Figure 3: Simulations in multi-physics workflow:
(a) EM simulation mesh used to determine heat generation as an input to the thermal simulator.
(b) FEM thermal/mechanical simulation mesh.
(c) Thermal simulation results showing temperature distribution.
(d) Mechanical stresses after phy sical deformation is computed from the thermal results.

Examples of Simulation vs. Measurement

Figure 4 shows a plot of S21 for an LTCC bandpass filter from a standard simulation model, Mini-Circuits advanced material simulation model and actual measured performance. The pink plot represents the simulation results without the material knowledge we've modelled into newer simulations. Note the disparity between this simulation and the measured performance. The red line represents Mini-Circuits' new simulation workflow incorporating all the material characterization and modelling we've conducted. Note that this simulation tracks the measured filter performance very closely across the full measured range.

Figure 4: Standard simulation and MCL material simulation vs. measured S21 performance of an LTCC bandpass filter after first spin manufacturing run.

Figure 5 shows additional comparisons between Mini-Circuits' advanced simulation results and measured performance for a different LTCC bandpass filter model. Both S21 and S11 are shown, illustrating highly accurate simulation results for both parameters. These cases are representative of the unique capability to achieve close agreement between simulation results and measured performance after the first design run from the fab.

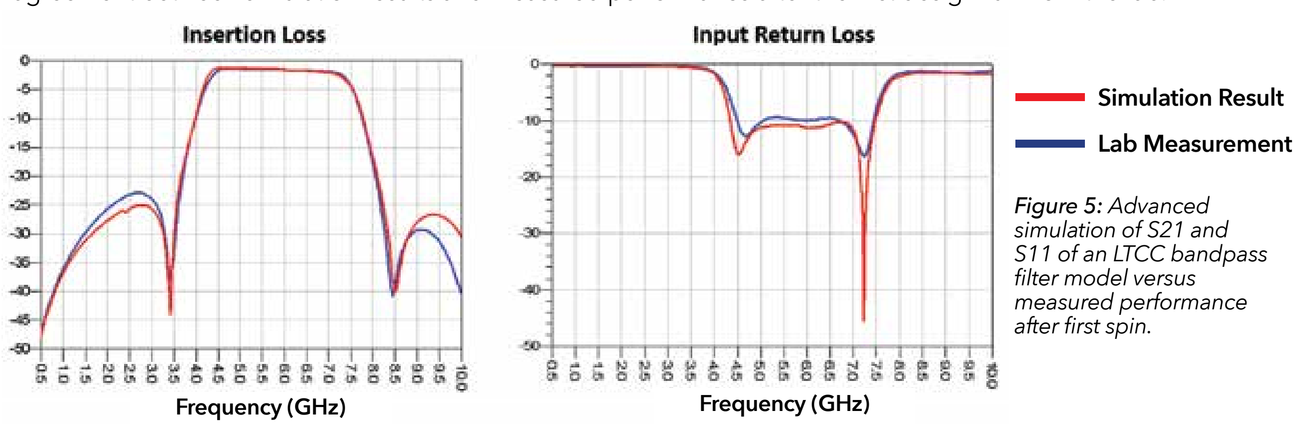


Figure 5: Advanced simulation of S21 and S11 of an LTCC bandpass filter model versus measured performance after first spin.

Extensions

The learnings illustrated above were shown for LTCC filter designs utilizing lumped topologies, but they have broad applicability for exploratory filter topologies and other technologies as well.

The recent shift to applications at higher and higher frequencies has necessitated exploration of distributed filter topologies. Genesys® offers filter synthesis for some of the known distributed topologies, but doesn't include synthesis and optimization tools for filters derived from Coupled Matrix Filter Synthesis Theory. At Mini-Circuits' we've taken many of the concepts from the research literature and created our own algorithm capable of synthesizing arbitrary distributed filter topologies based on our specs. We've also created an optimization tool capable of producing simulated S-parameters and optimized dimensions on a full 3D model.

We have extended the material simulations used for LTCC components to other technologies in our portfolio including MMIC and stripline architectures. The same capability is also a vital element of our active effort to develop advanced packaging solutions for surface-mount components on soft substrate up to 55 GHz.

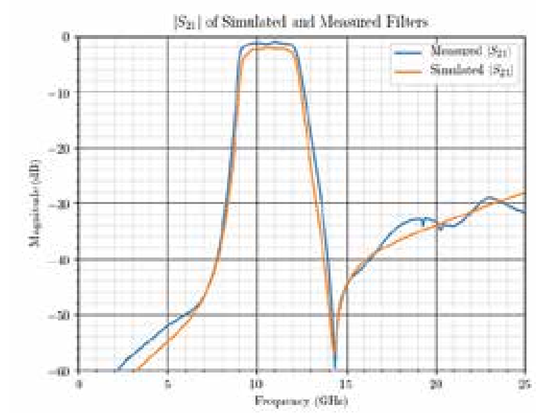


Figure 6: Simulated vs. measured performance of an LTCC combline bandpass filter after first spin.

Conclusion

Single pass success has long been considered the holy grail in design workflows. The physically complex nature of LTCC technology makes it particularly challenging to achieve agreement between simulation and working design on the first try. By using extensive material characterization and modelling together with advanced design tools, proprietary algorithms and our novel design workflow, our simulations now account for real world effects on performance to the degree that we can consistently achieve first-spin success in LTCC designs. Our capabilities in this area have helped us accelerate standard and custom parts to reduce customers' time to market and to enhance existing LTCC filter designs, reducing size and improving rejection performance. The design capability presented in this article extends to other technologies and innovations in high-frequency packaging solutions. These extensions will be addressed in greater depth in subsequent papers.

Inquiries: *apps@minicircuits.com*

SPLITTERS/ COMBINERS

HIGHLIGHTS

- 20W Ultra-Wideband Coaxial Splitter Combiners up to 40 GHz

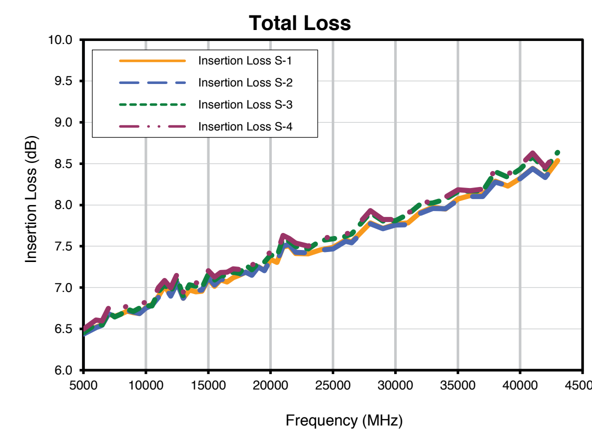
50Ω 6 to 40 GHz

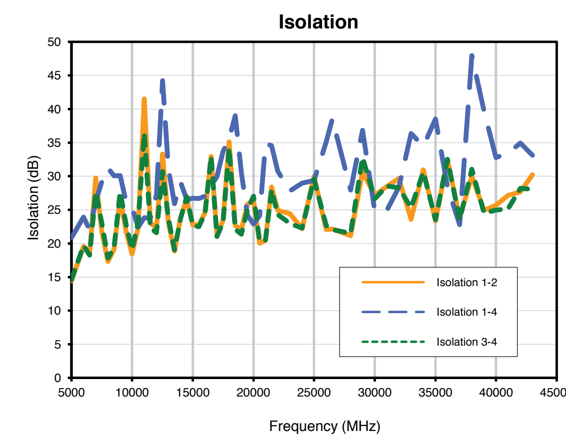
Ultra-Wideband Coaxial Splitter/Combiners

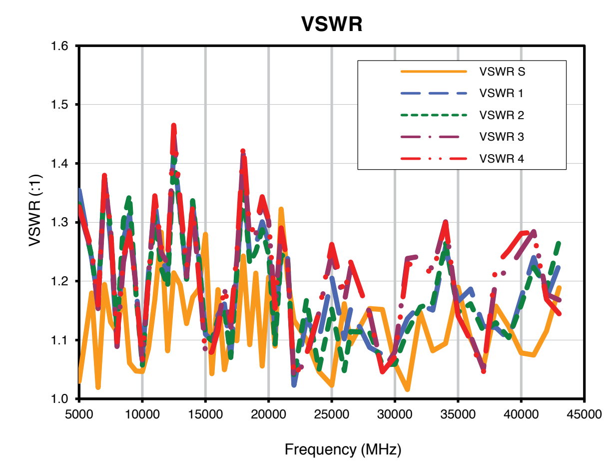
- Super wideband, up to 40 GHz
- Low insertion loss, as low as 0.8 dB
- High Isolation, up to 35 dB
- 20W power handling

Model Number	No. of Ways	Frequency Range GHz	Isolation (dB), Typ.	Insertion Loss (dB) Above Theoretical, Typ.	Phase Unbalance (deg), Typ.	Amplitude Unbalance (dB), Typ.	Power Input (W) as Splitter, Max.	Technology
ZC2PD-K1844+	2	18-40	27	0.8	1.1	0.05	20	-
ZC3PD-18263-S+	3	10-26.5	35	0.9	2.0	0.17	20	Stripline
ZC4PD-06263-S+	4	6-26.5	26	1.5	2.0	0.13	20	Stripline
ZC4PD-18263-S+	4	18-26.5	28	1.1	2.5	0.1	20	Stripline
ZC4PD-K0644+	4	6-40	26	1.5	2.9	0.13	20	Stripline
ZC6PD-K1844+	6	18-40	25	1.6	6.2	0.35	20	Stripline

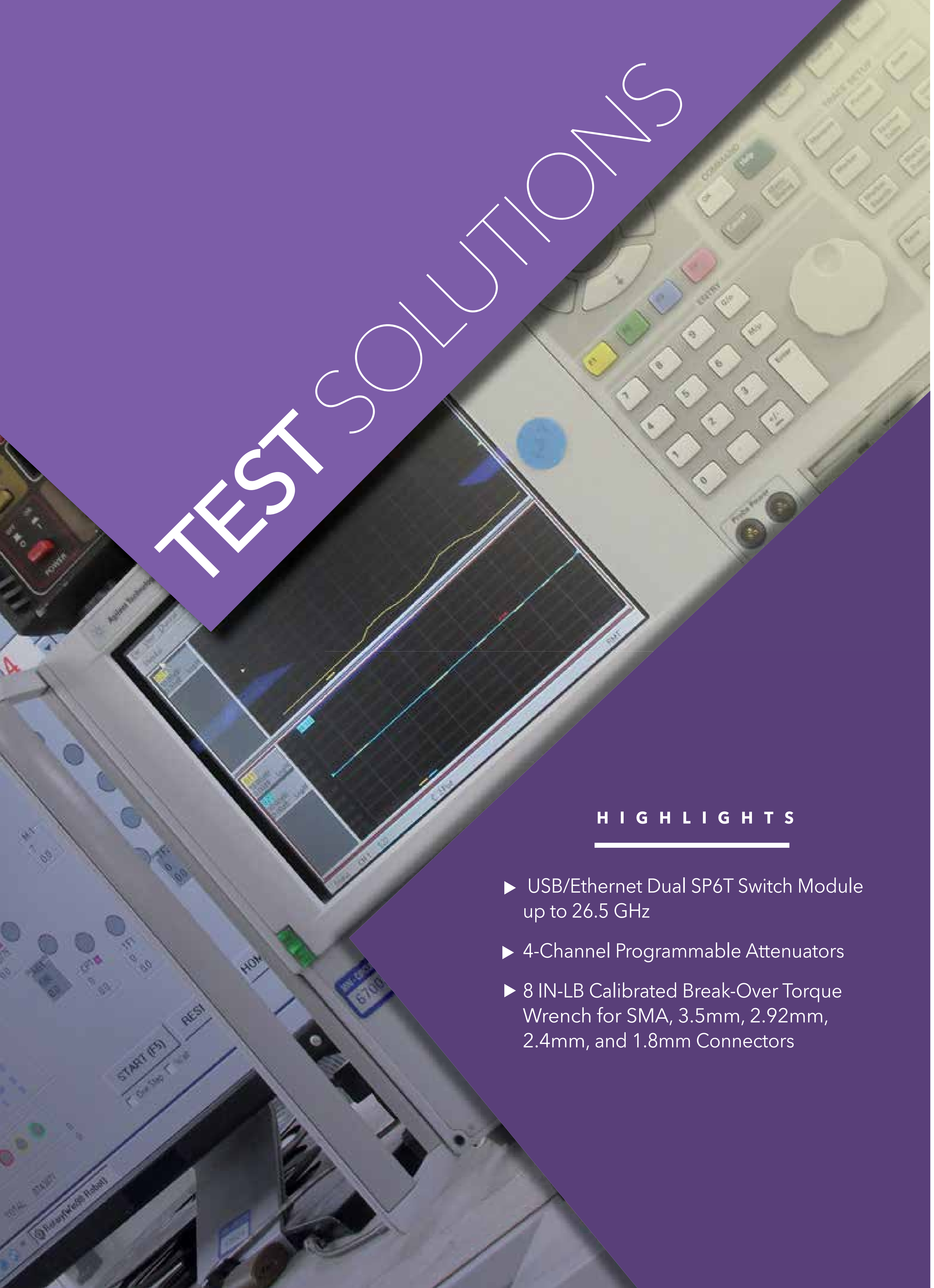
ZC4PD-K0644+







SPLITTERS/COMBINERS



H I G H L I G H T S

- USB/Ethernet Dual SP6T Switch Module up to 26.5 GHz
- 4-Channel Programmable Attenuators
- 8 IN-LB Calibrated Break-Over Torque Wrench for SMA, 3.5mm, 2.92mm, 2.4mm, and 1.8mm Connectors

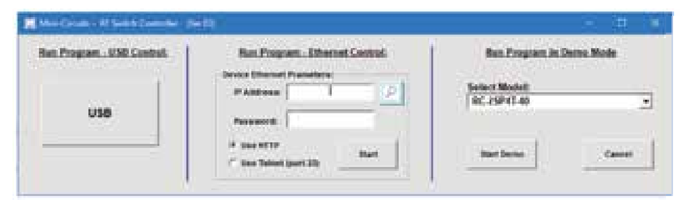
50Ω DC to 26.5 GHz

USB/Ethernet Dual SP6T Switch Module

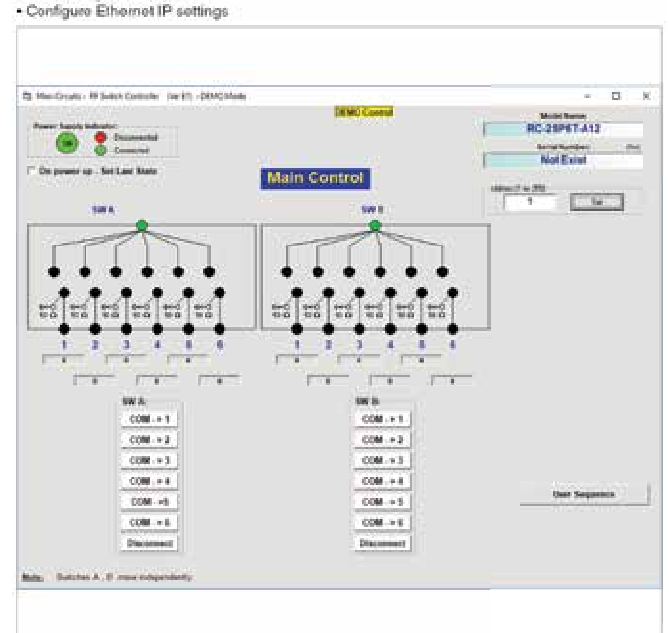
- Two independently controlled electromechanical SP6T switches
- High isolation (80-90 dB) and low insertion loss (0.25 dB)
- 5W power rating (cold switching)
- User friendly GUI and full API included

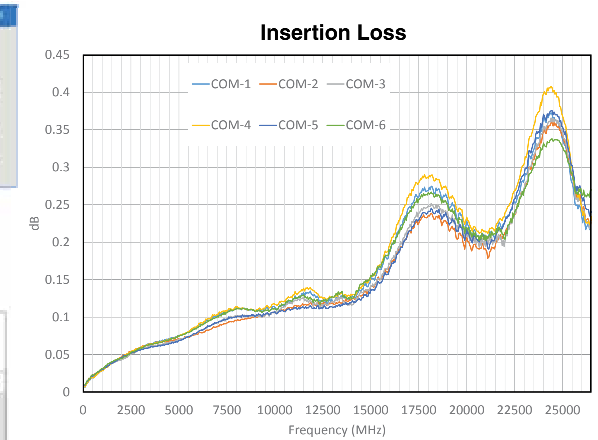
Model Number	Switch Type	Number of Switches	Control Interfaces	Frequency Range (GHz)	Insertion Loss (dB), Typ.	Isolation (dB), Typ.	VSWR (:1), Typ.	RF Power (W), Max.
RC-2SP6T-26	SP6T	USB & Ethernet	2	DC-26.5	0.25	90	1.35	20

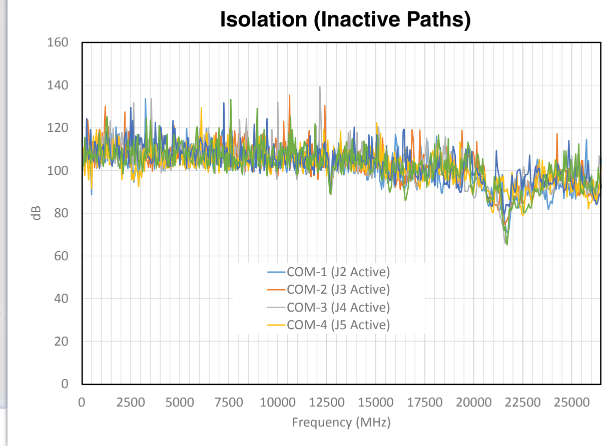
GUI Main Screen



- View and set switch states at the click of a button
- Configure and run timed switching sequences
- Set start-up switch state
- Configure Ethernet IP settings







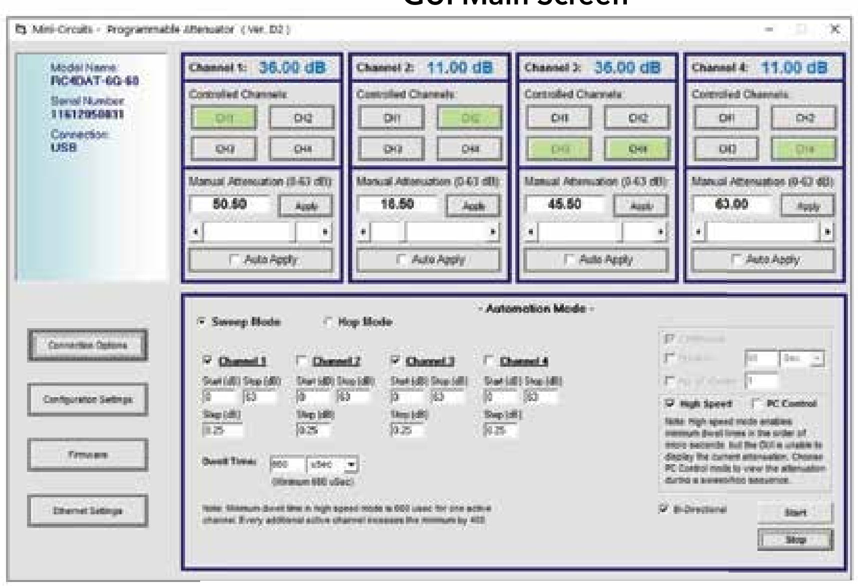
50Ω 0-95 dB, 0.25 dB Step, 1-6000 MHz

USB/Ethernet 4-Channel Programmable Attenuators

- Four independently programmable channels
- Wide attenuation range, up to 95 dB
- Fine attenuation resolution, 0.25 dB
- Ideal for MIMO test sets, automated test equipment, handover system evaluation and more!

Model Number	Control Interfaces	Number of Channels	Frequency Range (MHz)	Attenuation Range (dB), Typ	Attenuation Step (dB), Typ	Insertion Loss (0 dB Setting) (dB), Max	Attenuation Accuracy (dB), Typ	Max Input Power (dBm)	IP3 (dB), Typ
RC4DAT-6G-60	USB & Ethernet	4	1-6000	63	0.25	7.5	± 0.6	23	53
RC4DAT-6G-95	USB & Ethernet	4	1-6000	95	0.25	10.0	± 0.4	20	54
RC4DAT-6G-30	USB & Ethernet	4	1-6000	30	0.25	5.0	± 0.35	23	53

GUI Main Screen

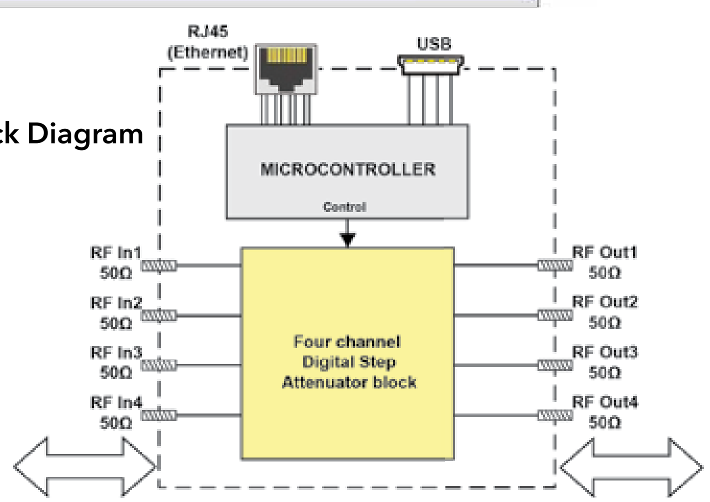


Graphical User Interface (GUI) for Windows

Key Features

- Manual attenuation setting
- Sweep and Hop attenuation sequences directed from the PC, or entire sequence loaded into RC4DAT.
- Attenuator address configuration and Firmware upgrade
- Attenuation at power up may be set to selected attenuation level or last attenuation state recorded.
- USB, HTTP or Telnet control of RC4DAT
- Setting Ethernet configuration

Block Diagram



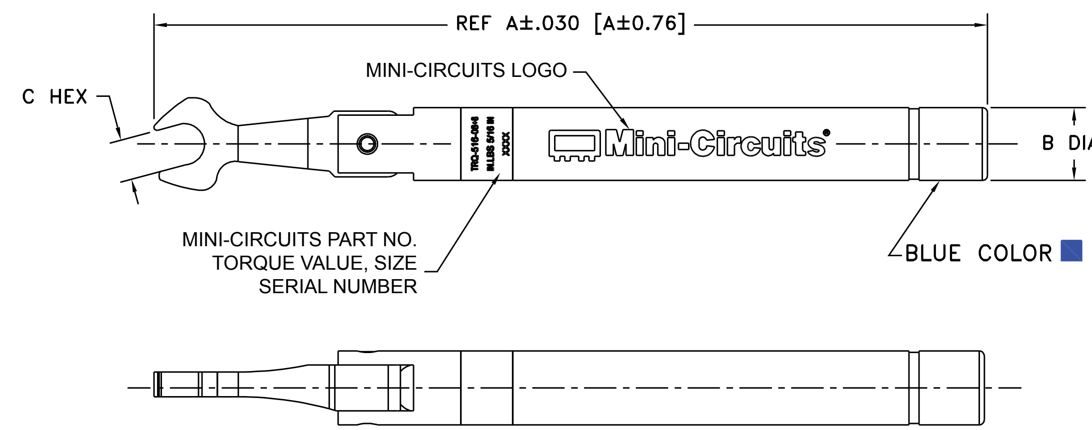
Simultaneous, bidirectional RF signal transmission with symmetrical performance

Break-Over Torque Wrench for SMA, 3.5mm, 2.92mm, 2.4mm & 1.8mm connectors

- Lab quality
- Precise preset torque, 8 IN-LB
- Prevents over or under tightening
- Light weight, easy to use in tight spots

Model Number	Case Style	Description	Torque (in-lbs)	Connector Type
TRQ-516-08	MY2727	Break-over Torque Wrench 8 in-lbs	8	SMA, 1.85mm, 2.4mm, 2.92mm, 3.5mm

Outline Drawing



Product Specifications

Wrench Torque	Case Style
Wrench Size	8±0.32 inch-lbs (0.9±0.04 NM)
Wrench Head	8.0 mm (5/16 inches)
Color	Stainless steel
Handle	Blue Handle
Length	6.44±.030
Weight	83.05 gms

Outline Dimensions (inch / mm)

A	B	C	wt
6.44	.563	.313	grams
163.6	14.3	8.0	83.05

The wrench kit consists of:
(1) Break-over torque wrench
(2) Calibration certificate*
(3) A solid wooden instrument case

** Recommended duration of calibration is one year. Calibration intervals set by national and international standards are either one year or 5000 cycles, whichever comes first. However, to ensure that the performance is in accordance to factory calibrated standards, actual need of calibration may vary based on use. Contact AM or RMA for recalibration.*

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