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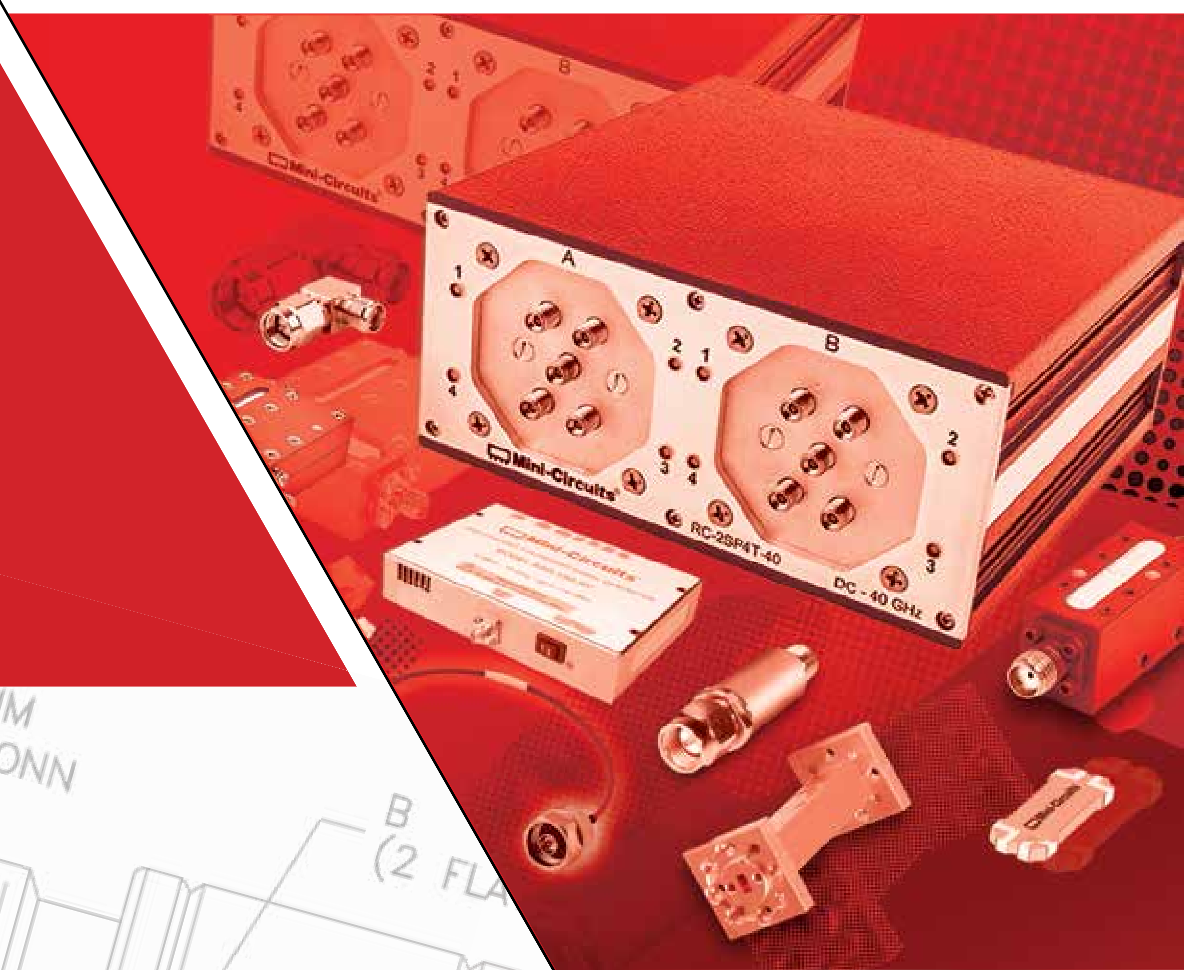
Q3
2019

NEW PRODUCT GUIDE



NPG19Q3

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HIGHLIGHTS

- New ultra-wideband MMIC LNAs
- MMIC LNAs with shutdown feature up to 43.5 GHz
- Multi-chip module integrates low pass reflectionless filter and two high-dynamic-range amplifiers
- New Class-AB high power amplifiers
- Ultra-wideband coaxial LNAs up to 20 GHz

50Ω 400 to 15000 MHz

Ultra-Wideband MMIC LNAs

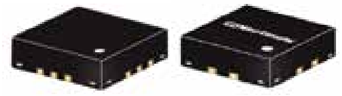
- Low noise over wide bandwidth
- Flat Gain
- High IP3

NEW RELEASE 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	5/6	50/66
PMA2-133LN+	10000-13000	15.3	1.3	13.5	28.6	1.24	1.08	3/5	13/29
PMA2-123LN+	500-12000	16.8	2.6	14.9	27	1.96	1.17	5/6	51/68
PMA2-123LN5+	500-12000	15.1	1.2	12.2	23.4	1.9	1.3	5	30
PMA3-83LN+	500-8000	22.1	1.3	20.7	35.2	1.38	1.58	5/6	60/77
PMA3-83LNW+	400-8000	22.6	1.2	21.7	37.0	1.32	1.5	5/6	58/75
PMA3-63GLN+	1800-6000	27.9	0.7	14.1	26.6	1.78	1.92	5	69
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	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
PMA2-162LN+	700-1600	22.7	0.5	20	30	1.3	1.3	4	55

50Ω 1 to 43500 MHz

Wideband MMIC Amplifiers with Shutdown

- Noise figure as low as 1.1 dB typ.
- Excellent gain flatness
- IP3 up to 42.9 dBm
- Internal shutdown feature protects the amplifier and reduces power consumption



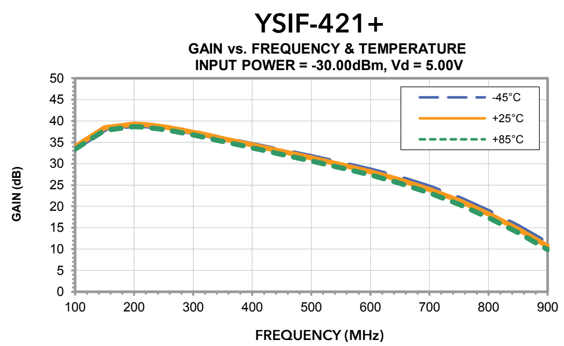
NEW RELEASE Model Number	Frequency Range (MHz)	Gain (dB) Typ.	NF (dB) Typ.	P1dB (dBm) Typ.	OIP3 (dBm) Typ.	Input VSWR (:1) Typ.	Output VSWR (:1) Typ.	Voltage (V)	Current (mA)
TSS-13HLN+	1-1000	23	1.4	28.4	42.9	1.43	1.37	8	234
TSS-13LN+	1-1000	22.8	1.1	24.5	39.2	1.28	1.32	5/3	142/72
TSS-23HLN+	30-2000	21.8	1.4	28.5	42.6	1.92	1.67	8	236
TSS-23LN+	30-2000	21.5	1.2	24.1	36.4	1.92	1.67	5/3	139/74
TSS-53LNB+	500-5000	21.7	1.4	20.6	33.9	1.46	1.33	5	82
TSS-53LNB3+	500-5000	18.4	1.5	14.9	25	1.63	1.26	3	42
TSS-183A+	5000-18000	14.2	4.4	17.9	28.9	1.37	1.28	5	145
TSS-44+	22000-43500	17.6	3.2	6.9	12.7	1.37	1.28	4	22

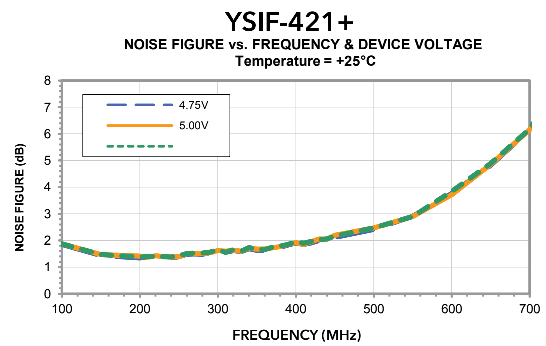
50Ω 220 to 380 MHz

High Gain Monolithic LNA

- Low noise, 1.6 dB typ.
- High cascaded gain, 37.2 dB typ.
- High IP3, 38.3 dBm typ.
- Multi-chip module integrates low pass reflectionless filter and two high-dynamic-range amplifiers in a single 5x5mm QFN

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)
YSIF-421+	220-380	37.2	1.6	22.2	38.3	1.78	1.08	5	189



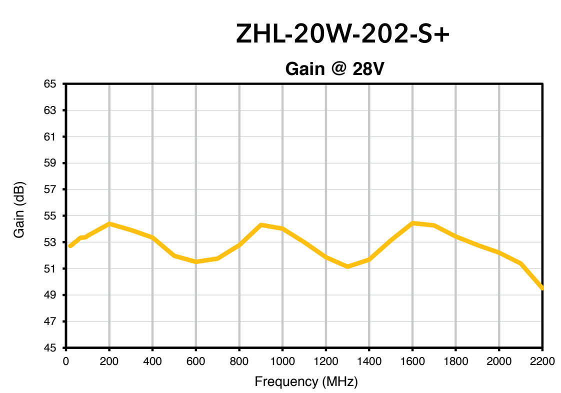


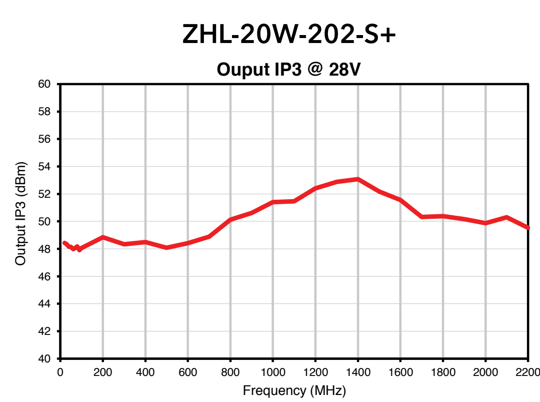
50Ω 10 to 2000 MHz

Class AB High Power Amplifiers

- Saturated POUT from 5W to 20W
- Self-protected from excessive drive, heat, reverse polarity and open/short loads
- High Gain, 50 dB typ.

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)
ZHL-20W-202-S+	20-2000	53	10	39	45	2.0	3.5	28	
ZHL-10W-202-S+	10-2000	50	10	38	45	2.0	2.0	28	
ZHL-5W-202-S+	10-2000	50	10	36	45	1.2	2.0	28	60



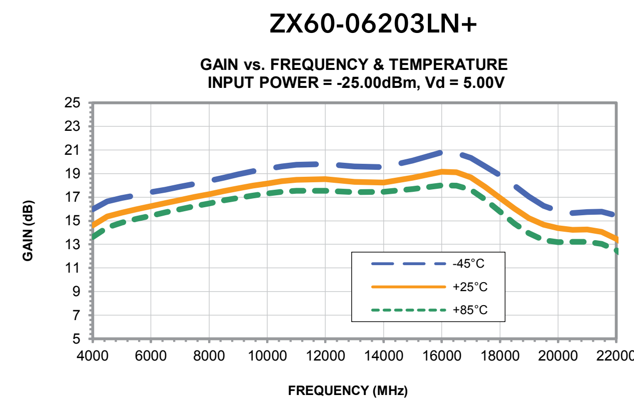


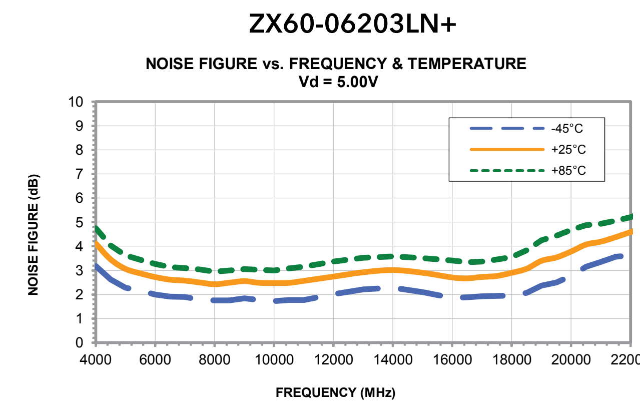
50Ω 500 to 20000MHz

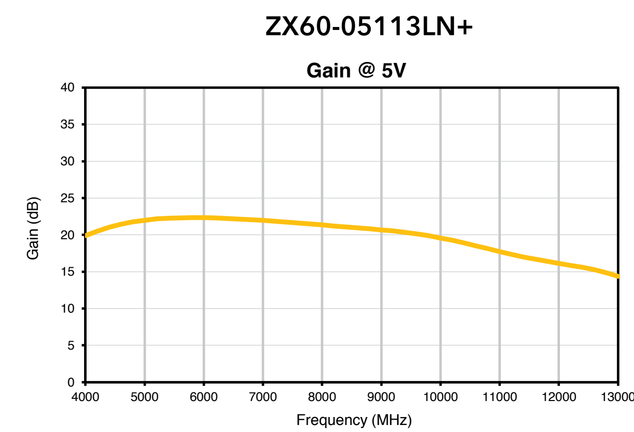
Ultra-Wideband Coaxial LNAs

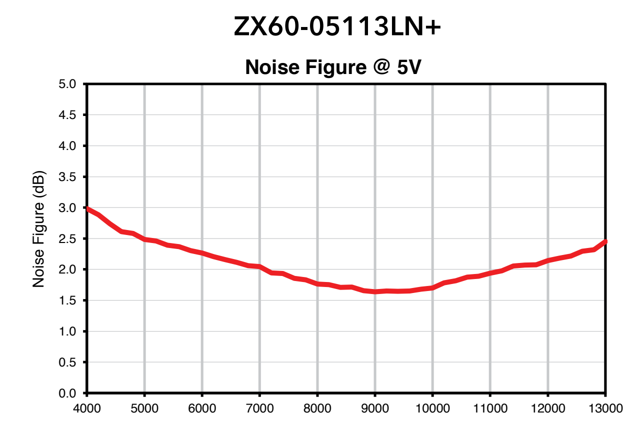
- Multi-octave bandwidths
- Very low noise over wide bandwidth
- Excellent gain flatness, ±1.6 dB or better
- High IP3, up to +35.2 dBm

NEW RELEASES 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)
ZX60-06203LN+	6000-20000	18.4	2.8	15.6	27.4	1.9	1.65	5	128
ZX60-06183LN+	6000-18000	25	2.1	11	24	2	2	5	64
ZX60-153LN-S+	500-15000	16	2.8	15	27	2	1.5	12	82
ZX60-123LN-S+	500-12000	17	2.4	16	28	1.45	1.3	12	82
ZX60-05113LN+	5000-11000	21.4	1.9	13	24.5	1.9	1.5	5	42
ZX60-83LN-S+	500-8000	22.1	1.4	20.7	35.2	1.38	1.58	5.0/6.0	60/70









COUPLERS

HIGHLIGHTS

▶ Expanded lineup of high-power stripline bi-directional couplers

50Ω 225-6000 MHz

High-Power Stripline Bi-Directional Couplers

- Flat coupling over multi-octave bandwidths
- High power in miniature, SMT case style
- Low insertion loss
- High directivity

NEW RELEASES Model Number	Frequency Range (GHz)	Coupling (dB) Nom.	Mainline Loss (dB) Typ.	Directivity (dB) Typ.	VSWR (:1) Typ.	Power Input Max. (W)
BDCH-10-63	2000-6000	10	0.1	22	1.12	100
BDCH-20-63+	2000-6000	19.5	0.15	19	1.2	180
BDCH-20-63A+	2000-6000	18	0.15	29	1.1	140
MBDC-13-63HP	2000-6000	12.8	0.1	23	1.15	100
MBDC-13-63HP+	2000-6000	12.8	0.1	23	1.15	100
MBDC-20-63HP	2000-6000	20.25	0.15	23	1.17	100
SCBD-10-63HP+	50-6000	10	0.9	17	1.22	100
SCBD-16-63HP+	50-6000	16.2	0.45	23	1.22	100
SCBD-16-562HP+	2700-5600	16.2	0.4	18	1.29	75
BDCH-25-33+	800-3000	25	0.2	28	1.2	150
BDCH-15-33+	500-3000	15.5	0.25	25	1.07	100
SCBD-20-272HP+	1750-2750	18.6	0.25	24	1.08	100
BDCH-15-272	700-2700	15	0.25	19	1.13	150
BDCH-20-272	700-2700	21	0.25	21	1.12	150
BDCH-25-272	700-2700	26	0.2	18	1.2	150
BDCH-35-272	700-2700	35	0.2	16	1.3	150
SCBD-25-122HP+	800-1220	25	0.1	23	1.07	100
SCBD-28-82HP+	600-820	28	0.1	23	1.07	100
SCBD-30-62HP+	400-620	31	0.08	23	1.1	100
MBDA-30-451HP	225-450	30.5	0.15	28	1.07	200

EQUALIZERS

HIGHLIGHTS

▶ Our popular wideband fixed gain slope equalizers are now available in both MMIC and tubular SMA connectorized formats to flatten system gain performance in your board design, cable assembly or test setup.

EQUALIZERS

50Ω DC to 6 GHz, 1 dB to 10 dB Slope Values

New ***SMA Connectorized Fixed Equalizers***

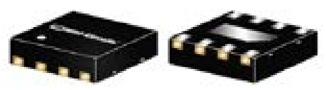
- Precise negative slope values over wide bandwidth
- Excellent VSWR
- +31 dBm power handling
- SMA connectorized housing ideal for cable assemblies and lab use

Model Number	Frequency Range (GHz)	Slope (dB) Typ.	Insertion Loss @ Freq. High (dB)	VSWR(:1) Typ.	Max Input Power (dBm)	Max Input Power (dBm)
VEQY-1-63+	10-6000	0.9	1	1.13	31	31
VEQY-2-63+	10-6000	2.3	0.6	1.18	31	31
VEQY-3-63+	10-6000	3	1.2	1.25	31	31
VEQY-4-63+	10-6000	4.4	0.8	1.23	31	34
VEQY-5-63+	10-6000	4.8	1.6	1.16	31	31
VEQY-6-63+	10-6000	6.3	1.1	1.2	31	31
VEQY-8-63+	10-6000	7.9	1.1	1.21	31	34
VEQY-10-63+	10-6000	9.9	1.6	1.21	31	31

50Ω DC to 20 GHz, 0 dB to 10 dB Slope Values

MMIC Fixed Equalizers

- Precise negative slope values over wide bandwidth
- Excellent VSWR
- Up to +34 dBm power handling
- Available in 2x2mm QFN and bare die formats



ez samples Try before you buy Model Number	Frequency Range (GHz)	Slope (dB) Typ.	Insertion Loss @ Freq. High (dB)	VSWR(:1) Typ.	Max Input Power (dBm)	Max Input Power (dBm)
EQY-0-24+	DC-20000	0.37	0.39	1.1	33	33
EQY-2-24+	DC-20000	2.1	0.9	1.16	31	31
EQY-3-24+	DC-20000	3.1	0.7	1.15	34	34
EQY-5-24+	DC-20000	5.1	0.7	1.24	34	34
EQY-6-24+	DC-20000	6.3	0.5	1.22	31	31
EQY-8-24+	DC-20000	8.3	0.8	1.18	34	34
EQY-10-24+	DC-20000	10.2	0.9	1.18	33	33
EQY-12-24+	DC-20000	12	1.4	1.09	30	30
ez EQY-0-63+	DC-6000	0.1	0.14	1.07	33	31
ez EQY-1-63+	DC-6000	1.2	0.4	1.24	31	31
ez EQY-2-63+	DC-6000	2.1	0.4	1.29	31	31
ez EQY-3-63+	DC-6000	3.2	0.6	1.29	31	34
ez EQY-4-63+	DC-6000	4.2	0.6	1.25	31	31
ez EQY-5-63+	DC-6000	5	1	1.24	31	31
ez EQY-6-63+	DC-6000	6.5	0.5	1.2	32	34
ez EQY-8-63+	DC-6000	8.2	0.5	1.21	31	31
ez EQY-10-63+	DC-6000	10.2	1	1.12	31	31

FILTERS

HIGHLIGHTS

- ▶ New ceramic resonator bandpass filters
- ▶ Reflectionless filters now available in connectorized housings
- ▶ New waveguide bandpass filters
- ▶ Expanded lineup of cavity filters
- ▶ Wideband suspended substrate diplexers

50Ω, 1333 to 2048 MHz

Surface Mount Ceramic Resonator 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 environments

New releases shown here. Over 50 models in stock. Custom designs available.

Model Number	Passband (MHz)	Lower Stopband (MHz)	Lower Rejection (dB)	Upper Stopband (MHz)	Upper Rejection (dB)
CBP-1423AF+	1333-1513	DC-1113	60	1669-2600	55
CBP-1475E+	1375-1575	DC-1230	40	1750-2600	40
CBP-1598AF+	1505.5-1690.5	DC-1264	60	1888-2900	60
CBP-1773AF+	1678-1868	DC-1400	65	2150-2700	60
CBP-1953AF+	1858-2048	DC-1500	65	2400-3500	50

50Ω, 2900 to 11500 MHz

SMA Connectorized Reflectionless Filters

- Matched to 50Ω in the stop band, eliminates undesired reflections
- New connectorized package supports cable assemblies and lab use

Model Number	Passband (MHz)	Passband VSWR (:1)	3 dB Cutoff (MHz)	Stopband (MHz)	Stopband VSWR (:1)	Rejection (dB)
VXHF-23+	2010-10100	2.0	1650	DC-1210	1.2	14
VXHF-292M+	2900-8700	1.9	8700	DC-1950	1.5	36
VXHF-392+	3940-11500	2.3	3220	DC-2450	1.6	12.5

50Ω, DC-19400 MHz

MMIC Reflectionless Filters

- Matched to 50Ω in the stop band, eliminates undesired reflections
- Cascadable
- Excellent power handling
- Ideal for non-linear circuits

New releases shown here. Over 80 models in stock!

Model Number	Type	Passband (MHz)	3 dB Cutoff (MHz)	Passband VSWR (:1)	Stopband (MHz)	Stopband VSWR (:1)	Rejection (dB)	Package
XHF-482M+	High Pass	4800-19400	4390	1.2	DC-3600	1.2	36	3x3mm QFN
XHF-73M+	High Pass	7000-16400	6420	1.1	DC-5200	1.1	30	3x3mm QFN
XHF-652M+	High Pass	6600-16200	6230	1.1	DC-5000	1.1	30	3x3mm QFN
XLF-662M+	Low Pass	DC-6000	6740	1.2	9200-26000	1.5	30	3x3mm QFN

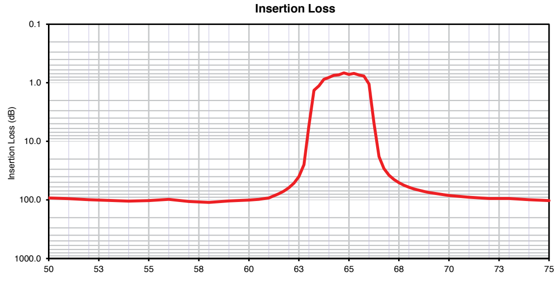
50Ω 27500 to 86000 MHz

Waveguide Bandpass Filters

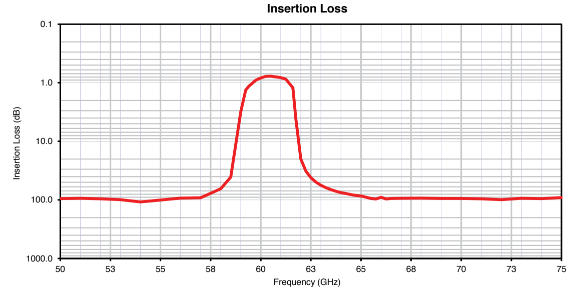
- Precision machining and plating
- Outstanding return loss
- Super-high rejection & fast roll-off

NEW RELEASES Model Number	Passband (MHz)	Lower Stopband (MHz)	Lower Rejection (dB)	Upper Stopband (MHz)	Upper Rejection (dB)
WVBP-833-WR12+	81000-86000	60000-79000	64	88000-90000	38
WVBP-783-WR12+	76000-81000	60000-74500	67	82500-90000	48
WVBP-733-WR12+	71000-76000	60000-69500	56	77500-90000	66
WVBP-673-WR12+	64000-71000	60000-61500	56	73500-90000	28
WVBP-653-WR15+	63700-65900	50000-62700	59	66900-75000	66
WVBP-613-WR15+	57200-65900	50000-56200	74	66900-75000	65
WVBP-633-WR15+	61500-63800	50000-60500	66	64800-75000	67
WVBP-64-WR15+	59400-61600	50000-58400	72	62600-75000	72
WVBP-583-WR15+	57200-59400	50000-56200	56	60400-75000	58
WVBP-383-WR28+	37000-40000	22000-36000	59	41000-42000	34
WVBP-283-WR28+	27500-28350	22000-27000	48	28850-38000	34

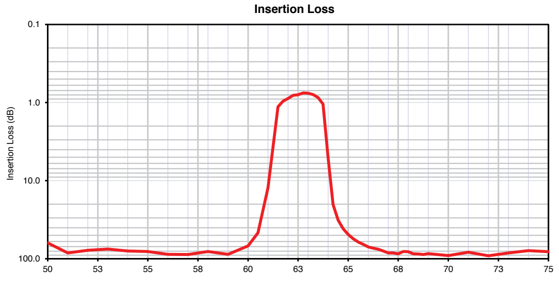
WVBP-653-WR15+



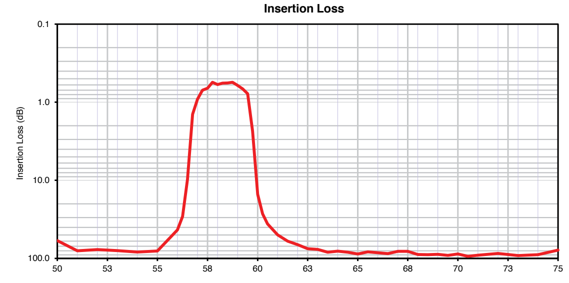
WVBP-64-WR15+



WVBP-633-WR15+



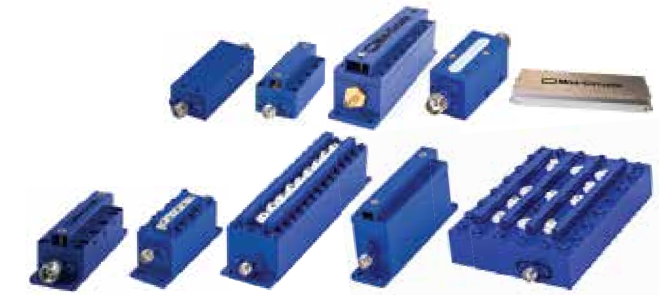
WVBP-583-WR15+



50Ω 902-19200 MHz

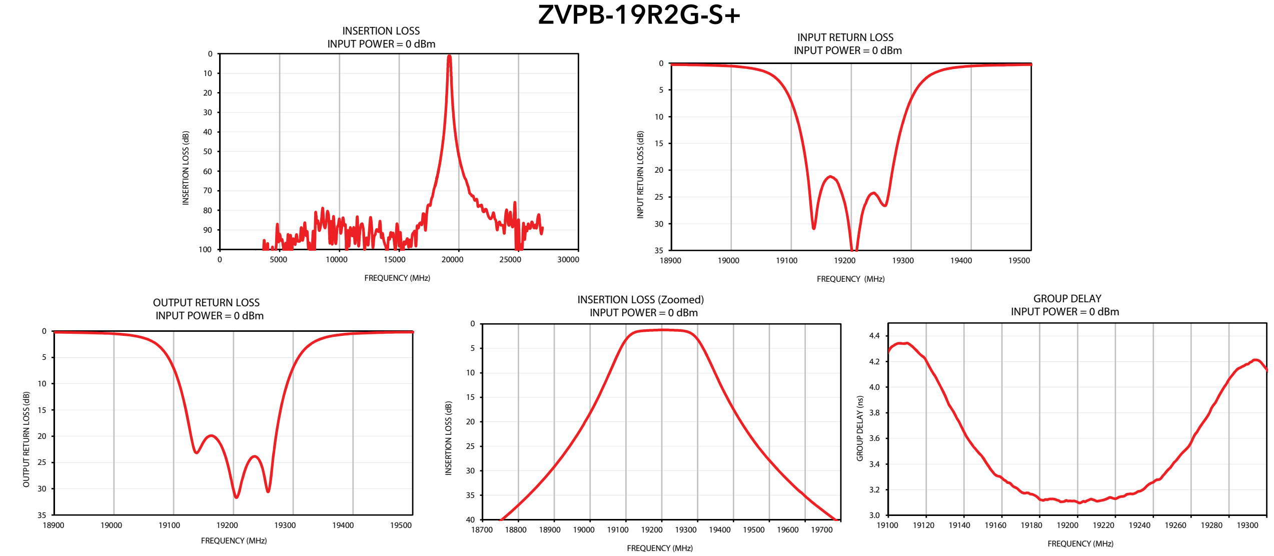
Cavity Bandpass Filters

- Passbands as narrow as 1%
- Very low passband insertion loss
- Very fast roll-off with wide stopband
- High power handling, up to 15W



NEW RELEASE Model Number	Passband (MHz)	Lower Stopband (MHz)	Lower Rejection (dB)	Upper Stopband (MHz)	Upper Rejection (dB)
ZVBP-19R2G-S+	19200	DC-18900	45	19500-27000	45
ZVBP-11G3-S+	11200-11400	DC-11030	35	11580-20000	35
ZVBP-10R5G-S+	9750-11250	DC-5950	35	15100-18000	35
ZVBP-8250-S+	8025-8475	DC-7650	20	8925-11000	20
ZVBP-5800-S+	5725-5875	DC-5200	35	6400-14000	35
ZVBP-5310-S+	5250-5370	DC-5080	20	5530-8250	20
ZVBP-4900-S+	4840-4960	DC-4670	20	5100-9000	20
ZVBP-4810-S+	4750-4870	DC-4600	20	5020-8250	20
ZVBP-4300-S+	4250-4350	DC-4140	20	4480-8000	20
ZVBP-4000-S+	3997-4003	DC - 3800	70	4200 - 6000	70
ZVBP-3875-S+	3845-3905	DC-3785	35	3970-8500	35
ZVBP-2450-S+	2400-2500	2120-2260	40	2635-2780	40
ZVBP-2400-S+	2375-2425	DC-2250	35	2550-6000	35
ZVBP-2300A-S+	2200-2400	DC-2000	30	2550-8050	30
ZVBP-909-S+	902-915	10-895	20	925-2300	20

ZVPB-19R2G-S+



50Ω 175 to 1580 MHz

Coaxial Bandpass Filters

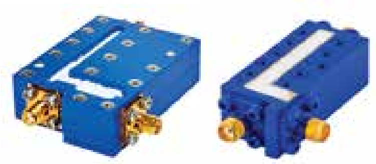
- Good rejection
- Wide stop band
- Excellent temperature stability

Model Number	Passband (MHz)	Lower Stopband (MHz)	Lower Rejection (dB)	Upper Stopband (MHz)	Upper Rejection (dB)
ZFBP-70HR-S+	69-71	DC-50	85	100-1000	60
ZX75BP-204-S+	175-237	DC-90	60	2500-3500	30
ZX75BP-A1060-S+	1015-1105	DC-880	25	1350-4000	30
ZX75BP-A1230-S+	1160-1300	DC-950	30	1670-3500	20
ZX75BP-B1230-S+	1120-1340	DC-940	25	1750-3500	20
ZX75BP-1450-S+	1320-1580	DC-1100	46	2000-2500	54
VBF-7331+	6850-7850	10-5800	23	9300-13300	20

50Ω DC -20000 MHz

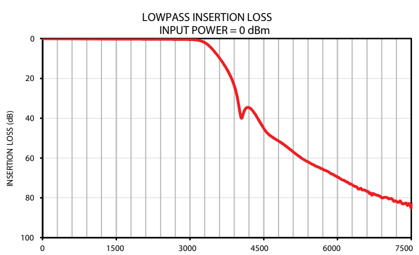
Suspended Substrate Diplexers

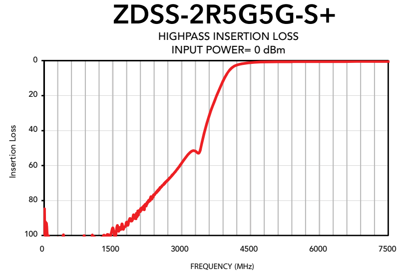
- Low insertion loss
- Ultra-wide passband width
- Fast roll-off with wide stopband
- Passband up to 26 GHz
- Stopband up to 26.5 GHz can extend to 40 GHz

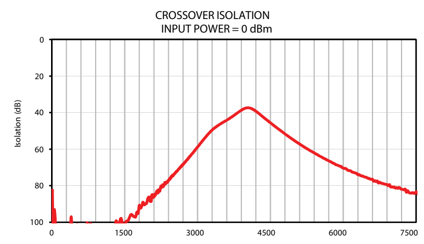


NEW RELEASE Model Number	Port	Passband (MHz)	Passband IL (MHz)	Rejection (dB)	Return Loss (dB)
ZDSS-5G6G-S+	High pass Low pass	DC-5000 6000-20000	1.5 2.5	80 @ 7200-20000 50 @ DC-4000	10 8
ZDSS-5G6G-S+	High pass Low pass	DC-3000 4000-20000	1.5 1.5	30 @ 4000-20000 15 @ DC-3000	10 10
ZDSS-2R5G5G-S+	High pass Low pass	DC-2500 5100-7500	0.5 0.8	50 @ 5100-7500 65 @ DC-2500	20 17

ZDSS-2R5G5G-S+







INTERCONNECT PRODUCTS

HIGHLIGHTS

- New flexible interconnect cables
- New SMA and N-Type adapters

50Ω DC-18000 MHz

Flexible Interconnect Cables

- Flexible construction ideal for integrating coaxial components in tight spaces
- Tight bend radius
- Excellent return loss and insertion loss

NEW RELEASES Model Number	Center Diameter	Length (ft.)	Connector 1	Connector 2	Frequency Range (MHz)	Insertion Loss (dB)
FL086-24NM+	0.086"	2.0	N-Type Male	N-Type Male	DC-18000	1.4
FL086-24SM+	0.086"	2.0	SMA Male	SMA Male	DC-18000	1.5
FL086-24SMNM+	0.086"	2.0	N-Type Male	SMA Male	DC-18000	1.4
FL086-12NM+	0.086"	1.0	N-Type Male	N-Type Male	DC-18000	0.6
FL086-12SM+	0.086"	1.0	SMA Male	SMA Male	DC-18000	0.9
FL086-12SMNM+	0.086"	1.0	N-Type Male	SMA Male	DC-18000	0.7
FL086-9SM+	0.086"	0.75	SMA Male	SMA Male	DC-18000	0.64
FL086-6NM+	0.086"	0.5	N-Type Male	N-Type Male	DC-18000	0.3
FL086-6SM+	0.086"	0.5	SMA Male	SMA Male	DC-18000	0.4
FL086-6SMNM+	0.086"	0.5	N-Type Male	SMA Male	DC-18000	0.3
FL141-24NM+	0.141"	2.0	N-Type Male	N-Type Male	DC-18000	0.9
FL141-24SM+	0.141"	2.0	SMA Male	SMA Male	DC-18000	1.0
FL141-24SMNM+	0.141"	2.0	N-Type Male	SMA Male	DC-18000	0.9
FL141-12NM+	0.141"	1.0	N-Type Male	N-Type Male	DC-18000	0.4
FL141-12SM+	0.141"	1.0	SMA Male	SMA Male	DC-18000	0.5
FL141-12SMNM+	0.141"	1.0	N-Type Male	SMA Male	DC-18000	0.4
FL141-9SM+	0.141"	0.75	SMA Male	SMA Male	DC-18000	0.37
FL141-6NM+	0.141"	0.5	N-Type Male	N-Type Male	DC-18000	0.2
FL141-6SM+	0.141"	0.5	SMA Male	SMA Male	DC-18000	0.3
FL141-6SMNM+	0.141"	0.5	N-Type Male	SMA Male	DC-18000	0.2

50Ω, models from DC-50 GHz

Coaxial Adapters

- Wide variety of connector types
- Excellent VSWR
- Rugged construction

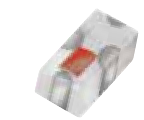
New releases shown here. Now over 50 models in stock!

Model Number	Connector 1	Connector 2	Frequency Range (GHz)	VSWR (:1) Typ.
NFFL-SM50+	N-Female	SMA-Male	DC-18	1.08
SFR-KF50+	SMA-Female	2.92mm-Female	DC-18	1.11
SFR-SM50+	SMA-Female	SMA-Male	DC-18	1.09

LTCC PRODUCTS

50Ω, 2400 to 2500 MHz

LTCC Directional Couplers



- Band optimized for Wi-Fi, Bluetooth and Zigbee
- Tiny size, 0603
- Excellent power handling, 2W

NEW RELEASES Model Number	Frequency Range (GHz)	Coupling (dB) Nom.	Mainline Loss (dB) Typ.	Directivity (dB) Typ.	VSWR (:1) Typ.	Power Input Max. (W)
CPJC-6-252R+	2400-2500	6.5	1.27	18	1.2	2
CPJC-10-252R+	2400-2500	10	0.65	19	1.33	2
CPJC-17-252R+	2400-2500	17.65	0.14	12	1.06	2
CPJC-21-252R+	2400-2500	21	0.3	19	1.1	2
CPJC-28-252R+	2400-2500	28	0.3	10	1.05	2

50Ω, DC to 6000 MHz

LTCC Diplexers

- Case styles as small as 0402
- Rejection up to 30 dB
- Channel splits for Wi-Fi, Bluetooth, Zigbee and more

NEW RELEASES Model Number	Port	Passband (MHz)	Passband IL (dB)	Rejection(dB) (MHz)	Return Loss (dB)	Package Size
DPGE-252-492R+	Low Pass High Pass	2400-2500 4900-5950	0.4 0.5	36 @ 4800-6000 25 @ 800-2500	33 25	0805
DPJC-252-492R+	Low Pass High Pass	2400-2500 4900-5950	0.7 0.7	28 @ 4800-6000 34 @ 800-2500	18 26	0603
DPNK-252-492R+	Low Pass High Pass	2400-2500 5150-5850	0.4 1.2	26 @ 4800-6000 40 @ 2400-2690	31 23	0402
LDP-1050-252+	Low Pass High Pass	1-1050 1650-2500	0.6 1	31 @ 1650 - 2500 21 @ 1-1050	15 8	1206
LDPG-212-322+	Low Pass High Pass	DC-2100 2600-5000	0.5 0.8	22 @ 3200 - 5000 18 @ DC - 2040	16 14	0805
LDPG-272-492+	Low Pass High Pass	DC-2700 4900-5750	0.5 0.7	30 @ 4800 - 8000 23 @ DC - 2700	16 14	0805
LDPW-162-242+	Low Pass High Pass	DC-1650 2400-6000	0.6 0.6	20 @ 2500 - 6000 15 @ DC - 1650	20 16	0603

HIGHLIGHTS

State-of-the-art design capability

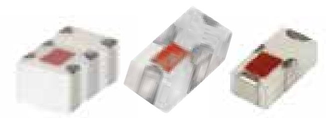
The industry's largest selection, over 440 models in stock

- Case styles as small as 0202
- Couplers
- Filters
- Splitters / Combiners
- Transformers / Baluns

50Ω, 2400 to 5950 MHz

LTCC Bandpass Filters

- Reduced package size, as small as 0402
- Enhanced rejection, up to 49 dB



Model Number	Passband (MHz)	Stopband F3 (MHz)	Rejection @ F3 (dB)	Stopband F4 (MHz)	Rejection @ F4 (dB)	Rejection (dB)	Package
BPGE-252R+	2400-2500	1200-1300	42	3600-3800	43	43	0805
BPGE-542R+	4900-5920	3500	49	14700-17760	30	30	0805
BPJC-252R+	2400-2500	1910	26	3200	38	38	0603
BPJC-542R+	4900-5900	DC-2700	40	9800-12000	34	34	0603
BPNK-252R+	2400-2500	692-800	40	4800-5000	23	23	0402
BPNK-542R+	4900-5950	2400-2500	23	14700-17850	38	38	0402

50Ω &75Ω, Passbands from DC to 4900 MHz

LTCC Low Pass Filters

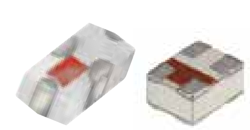
- Reduced package size, as small as 0402
- Enhanced rejection, up to 50 dB

Model Number	Passband F1 (MHz)	3 dB Cutoff (MHz)	Stopband F3 (MHz)	Rejection @ F3 (dB)	Stopband F4 (MHz)	Rejection @ F4 (dB)	Package Size
LFCG-1200+	DC-1200	1470	1865-3700	50	3700-10000	30	0805
LFCG-1400+	DC-1400	1650	2015-6600	50	6600-10000	35	0805
LFCG-1800+	DC-1800	2030	2450-7000	40	7000-10000	35	0805
LFCG-2500+	DC-2500	2870	3500-4000	33	7000-10000	30	0805
LFCG-2600+	DC-2600	3000	3850-7000	50	7000-15000	25	0805
LFCG-3000+	DC-3000	3460	4550-7000	50	11000-15000	25	0805
LFCG-3500+	DC-3500	3970	4800-5000	35	8500-15000	25	0805
LFCN-900+	DC -850	1075	1275	20	1350-4850	30	1206
LFCV-700-75+	5-700	855	990-1950	30	1950-2150	25	1210
LPGE-252R+	2400-2500	3750	4800-5000	40	7200-7500	37	0805
LPGE-592R+	4900-5900	7600	9800-11800	42	14700-17700	54	0805
LPJC-252R+	2400-2500	3600	4800-5000	52	7200-7500	34	0603
LPJC-592R+	4900-5950	7000	8800-12600	49	-	-	0603
LPNK-252R+	2400-2500	3100	4800-5000	42	7200-7500	40	0402

50Ω, 4900 to 5850 MHz

LTCC High Pass Filters

- Case styles as small as 0202
- Rejection up to 25 dB
- Passbands optimized for high-band Wi-Fi

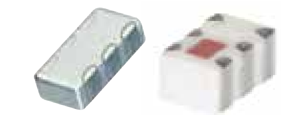


Model Number	Passband (MHz)	Stopband F3 (MHz)	Rejection @ F3 (dB)	Stopband F4 (MHz)	Rejection @ F4 (dB)	Package Size
HPJC-492R+	4900-5850	500-2400	25	2400-2500	36	0603
HPSC-492R+	4900-5850	500-2400	25	2400-2500	34	0202

50Ω, 600 to 5900 MHz

LTCC Splitter/Combiners

- Case styles as small as 0402
- Rejection up to 30 dB
- Channel splits for Wi-Fi, Bluetooth, Zigbee and more

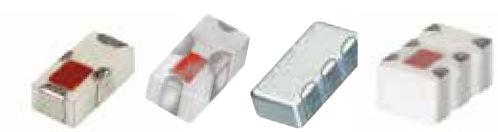


NEW RELEASES Model Number	Frequency Range GHz	No. of Ways	Isolation (dB), Typ.	Insertion Loss (dB) Above Theoretical, Typ.	Phase Unbalance (deg), Typ.	Amplitude Unbalance (dB), Typ.	Power Input (W) as Splitter, Max.	Package Size
SCG-2-242+	1000-2400	2	15	0.8	1.5	0.1	2	0805
SCG-2-322+	1800-3200	2	15	0.7	1.5	0.1	2	0805
SCG-2-592+	3800-5900	2	15	0.8	1.5	0.1	2	0805
SCG-3-162+	900-1600	3	18	1.2	5	0.2	2	0805
SCG-3-262+	1600-2600	3	17	1.2	5	0.4	2	0805
SCG-3-592+	4400-5900	3	17	1.2	5	0.4	2	0805
SCN-2-10+	600-1000	2	15	0.5	1.7	0.1	1	1206

50Ω, 223 to 5950 MHz

LTCC Transformers & Baluns

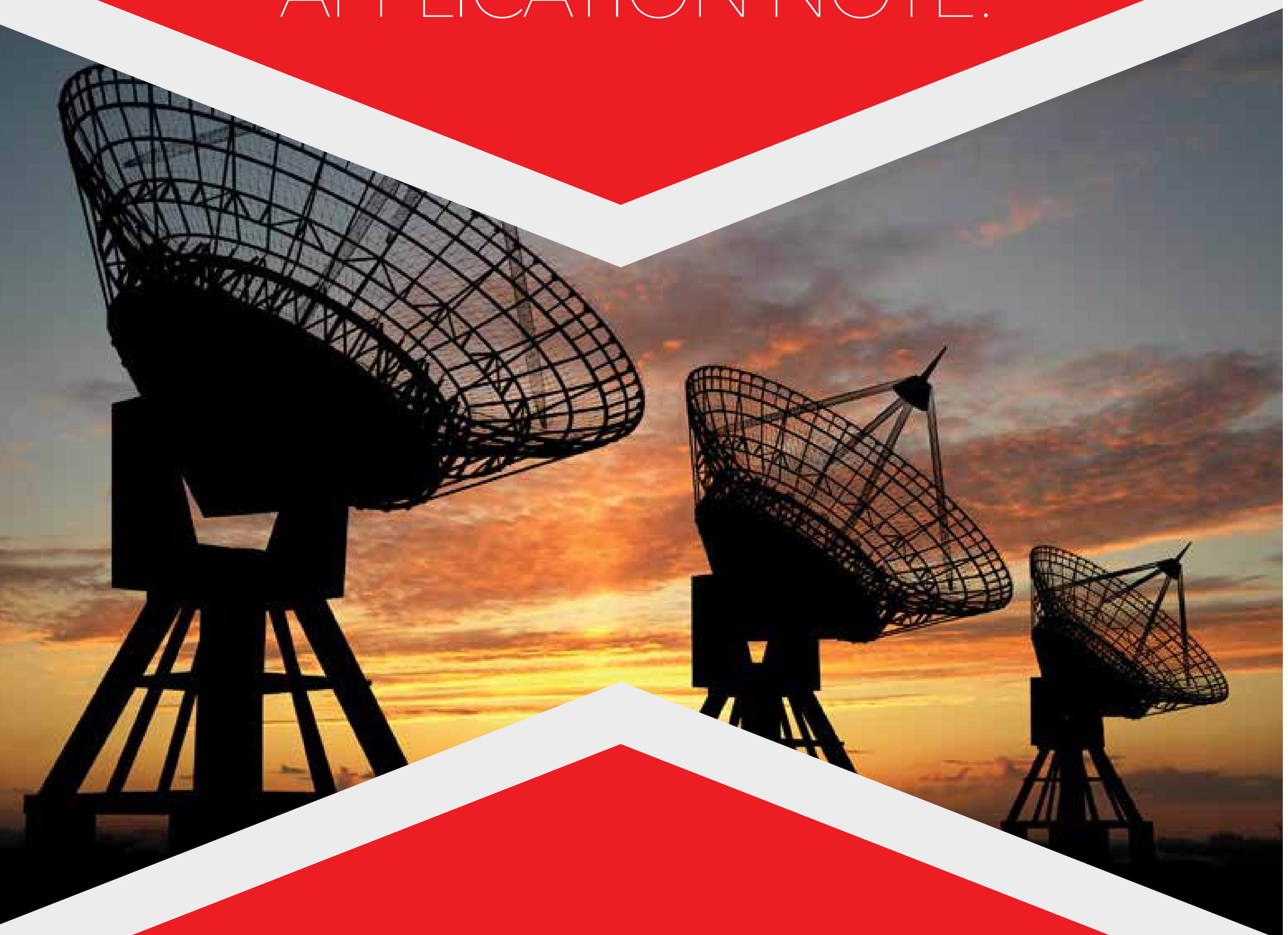
- Case styles as small as 0402
- Channel splits for Wi-Fi, Bluetooth, Zigbee and more



Model Number	Frequency Range (MHz)	Impedance Ratio	Single-Ended to Single-Ended	Single-Ended to Balanced	Balanced to Balanced	Center Tap	DC Isolation	Package Size
BLGE1-252R+	2400-2500	1	N	Y	N	N	Y	0805
BLGE1-542R+	4900-5875	1	N	Y	N	N	Y	0805
BLGE2-252R+	2400-2500	2	N	Y	N	N	Y	0805
BLGE2-542R+	4900-5875	2	N	Y	N	N	Y	0805
BLGE4-252R+	2400-2500	4	N	Y	N	N	Y	0805
BLGE4-542R+	4900-5875	4	N	Y	N	N	Y	0805
BLJC1-252R+	2400-2500	1	N	Y	N	N	Y	0603
BLJC1-542R+	4900-5950	1	N	Y	N	N	Y	0603
BLJC2-252R+	2400-2500	2	N	Y	N	N	Y	0603
BLJC2-542R+	4900-5875	2	N	Y	N	N	Y	0603
BLJC4-252R+	2400-2500	4	N	Y	N	N	Y	0603
BLJC4-542R+	4900-5950	4	N	Y	N	N	Y	0603
BLNK1-252R+	2400-2500	1	N	Y	N	N	N	0402
BLNK1-542R+	4900-5950	1	N	Y	N	N	N	0402
BLNK2-252R+	2400-2500	2	N	Y	N	N	N	0402
BLNK2-542R+	4900-5950	2	N	Y	N	N	N	0402
NCS1-521+	223-520	1	N	Y	N	N	N	0805
NCS4-521+	223-520	4	N	Y	N	N	Y	0805

LTCC PRODUCTS

APPLICATION NOTE:



A Practical Approach to the Design and Implementation of Scalable, High-Performance, Custom SMT Packages for mmWave Applications

ABSTRACT

After many years of research and development, electrical engineers, physicists, mathematicians and scientists have come to realize the benefits of operating communications systems at higher frequencies. Some of the most notable advances stemming from this research include: smaller circuit implementations for the same functionality; improved antenna gain for a given antenna size; and dramatic increases in data-carrying capacity. However, numerous challenges remain in implementing high-frequency circuits under real-world constraints. Among the non-trivial problems, packaging stands out.

It is critical that packages for RF components allow the integration of multiple circuital technologies while achieving the best possible balance of performance and cost for a given application. Nevertheless, traditional packaging techniques have proven incapable of translating the same performance typically seen below X-band into the millimeter wave range due to embedded parasitics and other inherent technological constraints. These limitations have led the design community to leverage new packaging technologies, novel design methodologies, and advanced CAD tools to develop cost-effective, scalable packaging solutions for high-frequency markets and applications. These new packaging techniques are now moving away from performance degrading implementations such as molding compounds and long wire bonding structures to achieve outstanding performance beyond 55 GHz. In light of these developments, this paper explores some of the key concepts underlying the development of commercially viable packaging solutions for millimeter wave components (patent pending).

Index Terms

Low-Temperature Co-Fired Ceramic, LTCC, MMIC, mmWave, Multi-Physics, Simulation, SMT Package, Packaging

I. INTRODUCTION

Global mobile data usage is expected to grow from 11.2 Petabytes/month in 2017 to 48.3 Petabytes/month in 2021. 5G has emerged as a strong proposal to achieve a 1000X increase in mobile data capacity and support the expected data consumption of seven billion people and seven trillion devices while remaining energy efficient and maintaining nearly-zero downtime[1]. The advent of 5G has brought about increasing development of integrated circuits (ICs) to meet the requirements for high frequency applications and a related need to develop cost-effective packages that not only protect the ICs, but are also capable of maintaining good electrical performance across wide operational frequency bands. Current surface mount QFN packages are not suitable for packaging devices at millimeter wave frequencies. Parasitic elements encountered in the signal path, for example discontinuities in the vertical transition from the PCB to the top side of the QFN and the wire bond to the IC, are negligible at lower frequencies but become relevant once the physical dimensions of the elements become a fraction of the wavelength. Another drawback of QFN packages is their reliance on over-molding, which not only increases electrical loss at higher frequencies, but also makes it impossible to package die featuring air-bridges. Moreover, QFN packages are incapable of accommodating flip chip devices due to their standardized nature. Many solutions have been developed in order to address these challenges: Air cavity QFN packages allow for ICs with air-bridges, but still lack a well-matched transition at high frequencies. MicroCoax structures [2] allow for high frequency operation, but require specialized assembly processes. Custom packaging solutions can compensate for parasitic effects [3] and allow for air-cavity implementation. Fully-custom solutions are most viable when incorporated into a rapid, low-risk design strategy as well as a highly-automated assembly process.

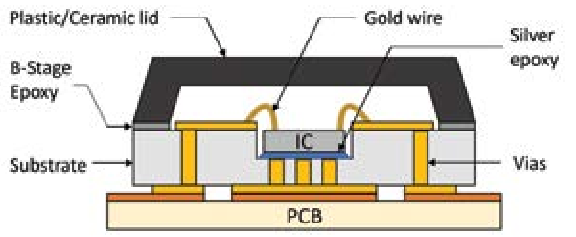


Fig. 1. Schematical cross section of ceramic package.

Modern RF applications have stringent requirements for components beyond electrical specifications; dense assemblies, high operating powers, and the need for robust, reliable systems place heavy demands on MMIC package designers to balance electrical performance with desirable thermal and mechanical characteristics. Since design features which benefit one aspect of performance may detract from the requirements of others, tradeoffs are often necessary. For example, a tradeoff intended to improve electrical performance at the expense of heat dissipation may yield little benefit due to the effect of a temperature rise on conductors and semiconductors. It is therefore critical for designers to understand the simultaneous effects of design choices on the different aspects of a device's performance

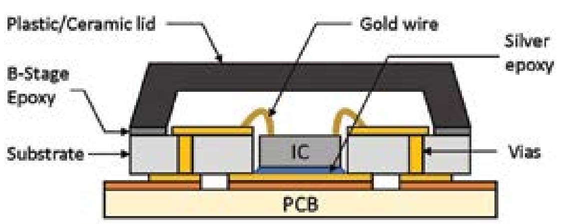


Fig. 2. Schematical cross section of organic package.

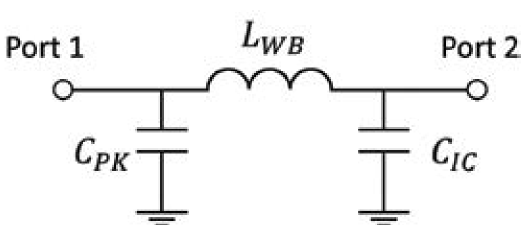


Fig. 3. Lumped element representation of the gold wire interconnect between the package pad (CPK), the gold wire (LWB) and the IC pad (CIC)

In this paper, we present the development of custom surface-mount packages with good electrical performance from DC to 50 GHz, accounting for the PCB, the surface mount package, and the IC (patent pending). Section II describes the package's components and design. Section III discusses the trade-off between customization and standardization of design features in the context of performance and cost goals. Measured performance of a broadband MMIC attenuator die in both custom organic and LTCC packages are shown. Additionally, the benefits of a multi-physics simulation workflow employed in the design of these packages are discussed.

II. DESIGN

A. Structure

Schematical cross section diagrams of the ceramic and organic packages and PCB are shown in Fig. 1 and Fig. 2, respectively. The following description is common to both. The IC is attached to the pocket inside the substrate using conductive epoxy. This implementation minimizes the length of the gold wirebonds. The gold wire interconnects the RF pads of the IC and the RF pads of the package, forming the low-pass network depicted in Fig. 3, where the wirebond is represented as a lumped series inductance LWB, and the pads are represented as CPK and CIC. Proper tuning of this matching network is critical for an accurate impedance match and good wideband electrical performance. The package's RF pad is followed by a microstrip line with 50Ω characteristic impedance, and a matched vertical transition down to the bottom pad. The bottom pad of the package is made to have a 50Ω characteristic impedance in a Grounded Coplanar Waveguide (GCPW) configuration. The package is soldered to the PCB, which has GCPW with a 50Ω characteristic impedance. A plastic or ceramic lid is attached to the package with a non-conductive B-staged epoxy.

B. Materials

Material and technology selection play a big role in the performance of a package. The selection of the right materials will depend on the application requirements such as hermeticity, maximum operating frequency, package size, package weight, first- and second-level interconnects, thermal management constraints, and tolerable insertion loss of interconnects [4]. In both the LTCC and organic substrate packages, the selection of substrate material must take into account the dielectric constant and loss tangent needed to achieve the desired RF performance. The substrate also determines the package topology and the compatibility with the other materials. The two substrates explored here are LTCC and organic substrate. The LTCC package, Fig. 1, consists of a ceramic monolithic structure with a cavity formed in the top tape layers of the substrate. The exposed top face of the pocket features a continuous metallization that is connected to the bottom ground pad through multiple vias. Being a stiffer material, it is easier to wire bond. In the case of the organic package, Fig. 2, the pocket is created by removing a portion of the substrate and exposing the bottom metallization, allowing for better RF grounding and thermal resistance.

In both packages, the conductor materials and finishes are selected to achieve good RF performance and to accommodate industry-standard assembly processes. The metal conductor on the LTCC package is typically silver with an Electroless Nickel Immersion Gold (ENIG) surface finish. The plating protects the underlying silver from oxidation and must also have properties compatible with soldering and wirebonding processes. The organic package employs copper conductors and may feature any of several different surface finishes. The choice of surface finish may be a critical matter in high frequency applications, as both surface roughness and electrical conductivity have significant effects on insertion losses [5] [6].

The selection of the conductive epoxy used to mount the MMIC die has a significant impact on the total thermal resistance of the package. As the main point of contact between the die and the package, the epoxy facilitates the majority of the die's heat dissipation.

C. Simulation Workflow

During the design phase of this project, the electrical,thermal, and mechanical performance of the LTCC and organic packages were analyzed using a multi-physics simulation workflow. The simulation workflow employed multiple simulators which were operated sequentially, with each simulator's results being used as part of the next simulator's setup.

The specific simulation workflow is as follows:

1) A full 3D finite-element electromagnetic simulation is performed on a simplified version of the design's geometry. The simulation yields S-parameter data and a spatial distribution of power dissipation within the design.

2) A full 3D finite-element thermal simulation is run on the electromagnetic simulation's model, augmented to include geometry relevant to thermal and mechanical (but not electrical) performance. As shown in Fig. 5, effort was made to accurately model critical regions of simulation geometry, such as hollow and solder-filled PTHs. The simulation employs the power dissipation computed from the electromagnetic simulation and yields a temperature distribution within the model's geometry.

3) A full 3D finite-element mechanical simulation is run on the full model geometry, employing the spatial temperature distribution as part of its setup. The simulation yields mechanical strains and stresses within the model geometry.

4) If desired, the above process may be iterated until convergence criteria are met, feeding the temperature rise information and model

LTCC PRODUCTS

geometry deformation into the electrical simulator for the next pass. In practice, a single pass is often sufficient to achieve outstanding agreement between simulation results and physical measurements.

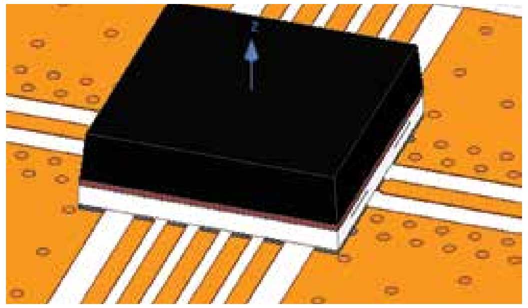


Fig. 4. Electromagnetic simulation model of LTCC package, including only the design elements relevant to electrical performance.

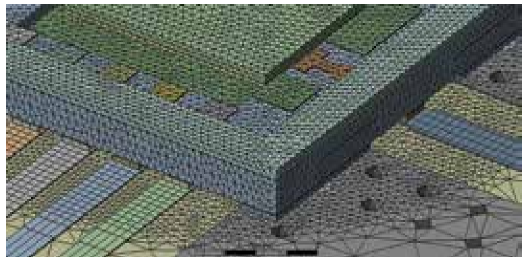


Fig. 5. Close-up of geometry and mesh employed in thermal and mechanical simulations of LTCC package, with package lid hidden. Note that the model includes solder, die-attach epoxy, and both hollow and solder-filled PTHs.

While more complex than a workflow involving separate electrical, thermal, and mechanical simulation tasks, a true multi-physics simulation workflow provides design engineers with a holistic view of a design's performance. For example, a traditional thermal simulation of a microstrip conductor may involve a uniformly-distributed heat source applied to the conductor's volume or faces. Such an approach discards valuable information about localized heat generation, since current densities at millimeter-wave frequencies are nonuniform. A multi-physics simulation approach implicitly captures this effect and others without needing attention from the designer.

The ability of a multi-physics simulation to automatically account for conditions too complex to set up manually is especially valuable for LTCC designs. As LTCC designs consist of a monolithic ceramic structure with complex internal conductor geometry, thermal images of the exterior of such a device may not fully reveal its internal thermal behavior.

Because the electrical, thermal, and mechanical aspects of a design's performance are often linked (due to temperature-dependent electrical resistivities, thermal expansion, and so on), such a simulation workflow makes it possible to best understand the impact of design decisions on interrelated aspects of performance. The workflow has been qualified through multiple projects involving several technologies, and achieves simulation results in very close agreement with performance measurements. As with other portions of Mini-Circuits' established LTCC process, it is subject to continual evaluation and improvement.

III. CUSTOMIZATION VS. STANDARDIZATION

Although the QFN package has been an industry workhorse for both active and passive electronic components up to V-band [7], its highly-standardized nature makes it a suboptimal solution for some applications. As applications march towards millimeter-wave frequencies, packaging technologies must adapt to widely-varying industry needs.

While a one-size-fits-all solution may fit all applications equally poorly, a fully-custom solution yielding outstanding results may be cost- and time-prohibitive. To develop a rapid, cost-effective packaging solution which still offers outstanding application flexibility, it was desirable to combine industry-standard processes and tunable design features into a customizable package template. This 'templated' approach to package design allows for the reuse of proven design elements, reducing the effort and risk incurred by from–scratch solutions. Facilities for adaptation to an application's specific electrical, thermal, mechanical, and environmental needs are provided while minimizing or eliminating the need for extensive qualification of new designs.

QFN packages are typically available in a granular range of standardized sizes (3mm x 3mm, 4mm x 4mm, and so on), while a MMIC die may be any size and aspect ratio. A die that is slightly too large to fit one standard QFN package size must instead use the next size up, necessitating long wirebonds with correspondingly large parasitic inductances. The package itself offers little facility to compensate for these parasitics, a task relegated instead to conductor geometry on the PCB and die. Furthermore, QFN packages employ a plastic encapsulant which envelops the leadframe, die, and wirebonds. Delicate structures on the MMIC die such as air bridges are incompatible with such an encapsulation process; even in the absence of incompatible MMIC features, the encapsulant may detune or degrade the performance of sensitive electronics simply by proximity. Finally, the terminals of the QFN package are highly standardized with little flexibility of the pad sizes and geometries. For some applications, the electrical parasitics associated with the fixed transition geometry may be unacceptable.

Mini-Circuits' custom LTCC and organic substrate packages address the above limitations, offering solutions with sufficient flexibility to meet the needs of a wide variety of applications. In these packages, the die inhabits a pocket atop the substrate as shown in Fig. 1 and Fig. 2. The pocket's dimensions are specified according to the customer's die so that wirebond pads can be brought as close to the die as possible, minimizing bondwire length and inductance. Therefore the LTCC and organic substrate packages offer greater flexibility with regard to MMIC die sizes even though they are currently available in the same sizes as standard QFN packages, 3mm x 3mm, 4mm x 4mm, and 5mm x 5mm. A plastic lid is affixed over the die and wire bonds with a B-staged epoxy compound, maintaining an air gap above the die and wirebonds and achieving a semi-hermetic seal. The use of an air gap rather than an encapsulant permits the packaging of delicate MMIC structures and minimizes degradation of electrical performance.

Unlike QFN packages, the LTCC and organic substrate packages offer the flexibility needed to best suit a wide variety of applications. The package structure contains tunable elements which electrically compensate for the parasitics associated with the transitions from the PCB to the package and from the package to the MMIC die. Furthermore, since the package features printed conductors rather than a solid leadframe, the footprints of the LTCC and organic substrate packages can be customized with minimal tooling cost.

IV. EXAMPLES

To validate the design and to measure the performance of the organic and LTCC packages, multiple packages were designed, fabricated, and tested. The packages were assembled and soldered on 5 mil Taconic TLY-5 evaluation PCBs with 50Ω CPWG traces. 2.4mm Southwest Microwave edge-launch connectors were used to interface the PCBs with the Vector Network Analyzer (VNA). Standard Short-Open-Load-Thru (SOLT) calibration was performed up to 55 GHz, up to the reference plane of the connectors. The insertion loss measurements for each package are normalized by subtracting the losses of the PCB thru-line.

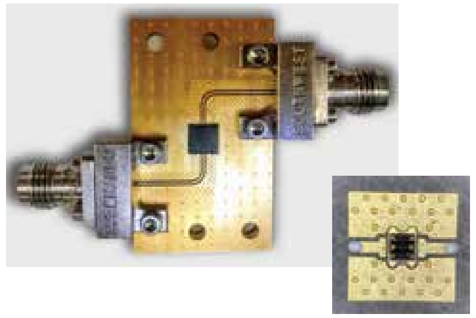


Fig. 6. IC in organic package on evaluation board. (a) Package with lid on evaluation board. (b) Close-up of package without lid, showing flip chip die atop package substrate.

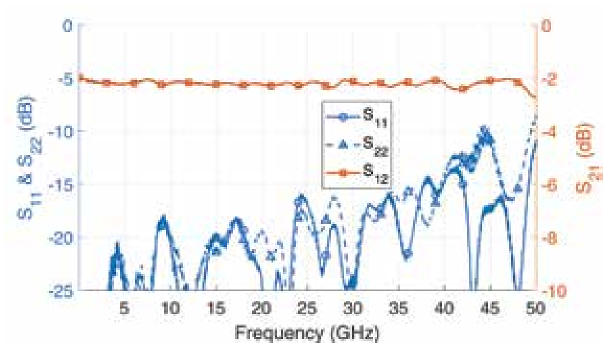


Fig. 7. Measurement results of 2 dB attenuator on organic package.

A. MMIC 2 dB Attenuator on Organic Package

A 2 dB MMIC attenuator is mounted and wirebonded on top of an organic package. Fig. 6 shows the package mounted on top of the PCB, as well as a close up of the package without the lid, showing the die and the wirebonds. Fig. 7 shows the measured data of the device. The S21 trace shows a very flat response of −2 dB up to 48 GHz. A good return loss is also observed for the entire frequency bandwidth.

B. MMIC 2 dB Attenuator on Ceramic Package

A 2 dB MMIC attenuator is mounted and wirebonded on top of a ceramic package. Fig. 8 shows the package mounted on top of the PCB, as well as a close up of the package without the lid, showing the die and the wirebonds. Fig. 9 shows the measured data of the device. The S21 trace shows a very flat response of −2 dB up to 55 GHz. A good return loss is also observed for the entire frequency bandwidth.

C. Flip-Chip SPDT Switch on Ceramic Package

A flip-chip SPDT switch is mounted on top of an ceramic package. Fig. 10 shows the package mounted on top of the PCB, as well as a close up of the package with the exposed flip-chip die. Fig. 11 shows the measured data of the device with the RF2 channel active. A good return loss is observed over the entire bandwidth.

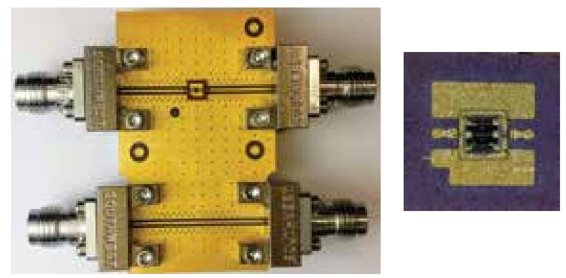


Fig. 8. IC in LTCC package on evaluation board. (a) Package without lid on evaluation board. (b) Close-up of package without lid, showing die and wirebonds.

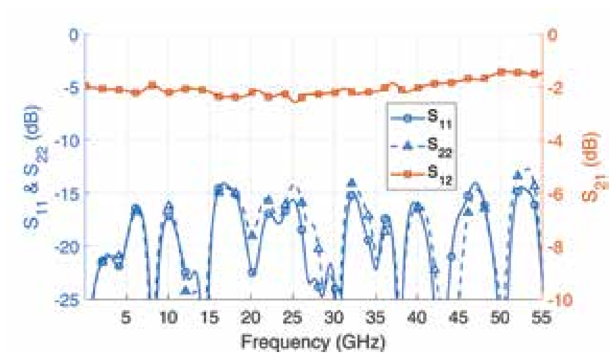


Fig. 9. Measurement results of 2 dB attenuator on LTCC package.

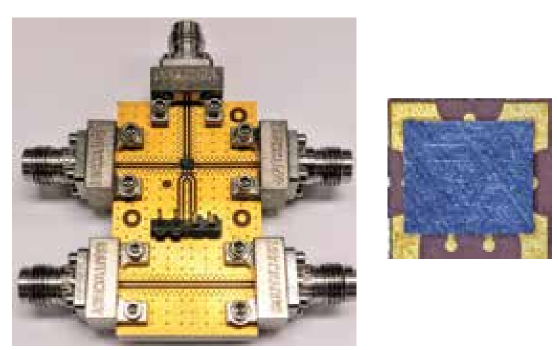


Fig. 10. Packaged IC on evaluation board. (a) Package with lid on evaluationboard. (b) Close-up of package without lid, showing die and wirebonds.

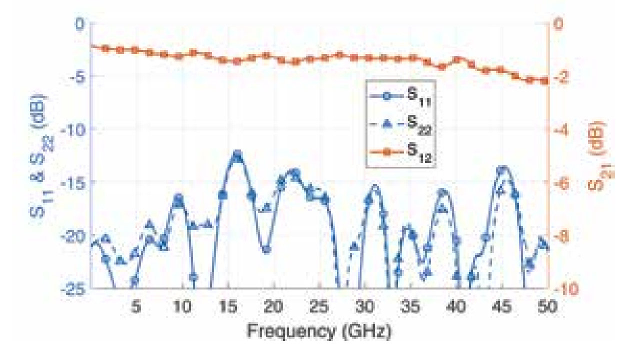


Fig. 11. Measurement results SPDT flip-chip switch with RF2 channel active.

V. CONCLUSION

Packages employing both LTCC and organic substrate materials have been developed (patent pending). Outstanding electrical performance of both packaging technologies has been demonstrated up to 55 GHz. Both packaging methodologies accommodate a wide variety of application-specific needs, including impedance-matching, variable die sizes, and a wide range of IO pad counts, signal types (DC or RF), and PCB geometries. By combining standardized and adjustable features into a tunable package template, Mini-Circuits' approach to packaging achieves desirable electrical performance and broad applicability while minimizing turnaround time, cost, and risk.

VI. ACKNOWLEDGEMENTS

The authors would like to thank Mini-Circuits for providing the resources needed to conduct the research and develop the innovations presented in this paper.

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LTCC PRODUCTS

SPLITTERS/ COMBINERS

HIGHLIGHTS

- 0°/180° Magic-T for DOCSIS® 3.1 applications
- Ultra-wideband coaxial splitter/combiners, 3-way to 16-way up to 40 GHz.

75Ω, 5 to 1218 MHz

0°/180° Magic-T Splitter/Combiner

- Low amplitude unbalance, 0.3 dB
- Low phase unbalance, ±3°
- Good power handling, 0.5W
- Supports bandwidth requirements for DOCSIS® 3.1

Model Number	Frequency Range (MHz)	Isolation (dB), Typ.	Insertion Loss (dB) above 3 dB, Typ.	Phase Unbalance (deg), Typ.	Amplitude Unbalance (dB), Typ.	Power Input (W) as Splitter, Max.
SYMT-122-75+	5-1218	20	3.2	7	0.6	0.5

50Ω, 0.5 to 40 GHz

Ultra-Wideband Coaxial Splitter/Combiners

- Low amplitude unbalance, 0.3 dB
- Low phase unbalance, ±3°
- Good power handling, 0.5W
- Supports bandwidth requirements for DOCSIS® 3.1

Model Number	Frequency Range GHz	Isolation (dB), Typ.	Number of Ways	Insertion Loss (dB) Above Theoretical, Typ.	Phase Unbalance (deg), Typ.	Amplitude Unbalance (dB), Typ.	Power Input (W) as Splitter, Max.
ZC3PD-K1844+	18000-40000	31	3	1.2	3.7	0.15	13.6
ZC4PD-K0144+	1000-40000	33	4	1.8	1.5	0.1	20
ZN4PD-K44+	10000-40000	22	4	1.5	6	0.3	20
ZC8PD-5R263-S+	500-26500	35	8	4.1	3.1	0.2	20
ZC8PD-01263-S+	1000-26500	26	8	3.2	2.9	0.14	20
ZC8PD-02263-S+	2000-26500	31	8	2.1	2.3	0.11	20
ZC8PD-06263-S+	6000-26500	28	8	1.2	2.6	0.11	20
ZC8PD-18263-S+	18000-26500	26	8	1.7	4.2	0.19	20
ZC8PD-K5R44W+	500-40000	35	8	4.1	1.9	0.18	20
ZC8PD-K0644+	6000-40000	28	8	2.0	2.2	0.12	20
ZN8PD-K44+	10000-40000	20	8	2	8	0.3	20
ZC8PD-K1844+	18000-40000	26	8	1.8	5.3	0.16	20
ZC16PD-06263-S+	6000-26500	24	16	2.2	3.3	0.2	20
ZC16PD-18263-S+	18000-26500	23	16	3.1	3.8	0.24	20
ZC16PD-K0644+	6000-40000	26	16	2.2	6	0.28	20
ZC16PD-K1844+	18000-40000	22	16	3.1	5.9	0.2	20

TEST SOLUTIONS

HIGHLIGHTS

- ▶ USB/Ethernet switch modules to 40 GHz
- ▶ Programmable attenuators up to 40 GHz
- ▶ New ultra-wideband synthesized signal generator, 10 to 15000 MHz, -50 to +15 dBm

50Ω DC to 40 GHz

USB/Ethernet Switch Modules

- Ideal for signal routing in high-frequency test setups
- Low insertion loss and high isolation
- User-friendly GUI and full API included

NEW RELEASES Model Number	Frequency Range (GHz)	Switch Type	Number of Switches	Insertion Loss (dB), Typ.	Isolation (dB), Typ.	VSWR (:1), Typ.	RF Power (W), Max.	Case Style
RC-1SP6T-26	DC-26.5	SP6T	1	0.25	90	1.35	20	PF2909
RC-2SP4T-40	DC-40	SP4T	2	0.3	80	1.3	20	MR2616
RC-2SP4T-26	DC-26.5	SP4T	2	0.2	80	1.35	20	MR2616
RC-2SP6T-26	DC-26.5	SP6T	2	0.25	90	1.35	20	PF2675
RC-2SP6T-40	DC-40	SP6T	2	0.4	80	1.7	20	PF2675

50Ω DC to 40 GHz

USB/Ethernet Programmable Attenuators

- Covering applications from 1 MHz to 40 GHz
- Precise attenuation control up to 120 dB
- Ideal for transmission loss simulation for a wide range of test applications
- User-friendly GUI and full API included

Model Number	Frequency Range (MHz)	Control Interface	Number of Channels	Attenuation Range (dB), Typ	Attenuation Step (dB), Typ	Attenuation Accuracy (dB), Typ	Max Input Power (dBm)	IP3 (dB), Typ
RC4DAT-8G-95	1-8000	USB & Ethernet	4	95	0.25	± 0.8	28	51
RCDAT-30G-30	1-30000	USB & Ethernet	1	30	0.5	± 0.8	24	38
RCDAT-40G-30	1-40000	USB & Ethernet	1	30	0.5	± 1.0	24	38

50Ω, 1 to 15000 MHz

USB/Ethernet Synthesized Signal Generators

- Wideband with fine frequency resolution
- Internal and external pulse modulation
- Sweeping and hopping capability
- Ideal for lab and field test equipment, ATE, design verification and more
- User-friendly GUI and full API included

NEW RELEASE Model Number	Frequency Range (MHz)	Power Range (dBm)	Frequency Resolution (Hz), Min.	Power Resolution (dB), Nom.	Harmonics & Sub-Harmonics (dBc), Typ.	Non-Harmonic Spurious (dBc) @ 100 kHz Step, Typ.	Phase Noise (dBc/Hz)SSB @ 100 Hz Offset, Typ.	Phase Noise (dBc/Hz) SSB @ 1/10/100 kHz Offset, Typ.
SSG-15G-RC	10-15000	-50 to 15	0.1	0.1	-25	-70	-83	-103/-112/-112
SSG-6000RC	25-6000	-65 to 14	3	0.25	-52	-72	-82	-96/-99/-102
SSG-6001RC	1-6000	-70 to 15	3	0.25	-65	-73	-92	-108/-112/-119

TRANSFORMERS & BALUNS

HIGHLIGHTS

- ▶ Tiny, surface-mount core-and-wire transformers
- ▶ 50/75Ω matching transformer, BNC-M to BNC-F

50Ω and 75Ω, 5 to 1500 GHz

Surface Mount Transformers

- Small footprint
- Wideband with flat response
- Good amplitude and phase unbalances

Model Number	Single Ended to Single Ended	Single Ended to Balanced	Balanced to Balanced	Center Tap?	DC Isolation?	Frequency Range (MHz)	Impedance	Impedance Ratio
SYTX2-451-5W+	N	Y	Y	N	Y	10-450	50	2
TC1-1T-152X+	N	Y	N	Y	N	5-1500	50	1
TRC1-1-122-75+	N	Y	N	N	N	5-1250	75	1

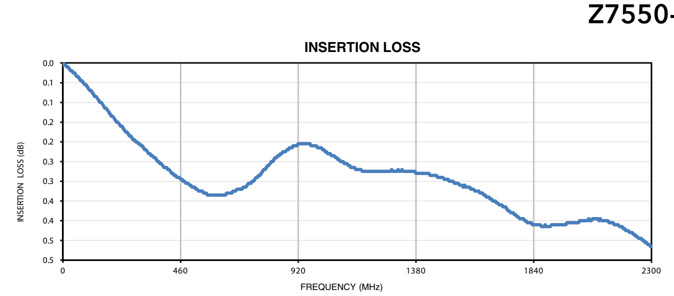
50Ω / 75Ω Matching Transformer

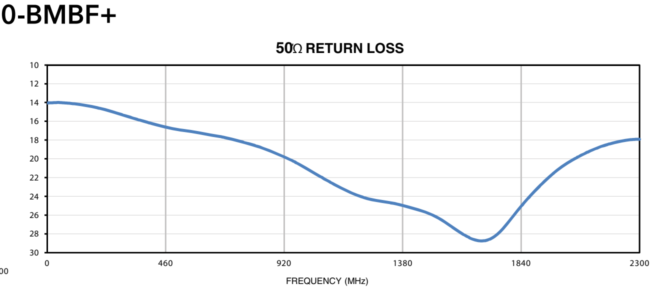
DC to 3000 MHz

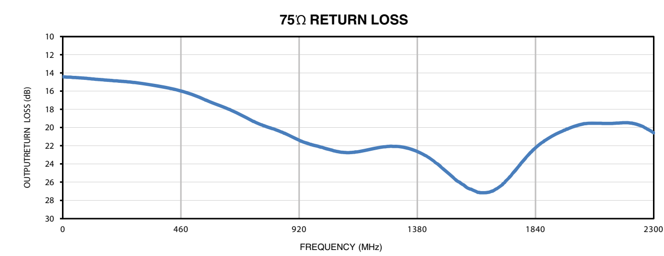
- BNC-male (50Ω) to BNC-female (75Ω) connectors
- Low insertion loss, 0.6 dB
- 2W power handling
- DC passing

Model Number	Frequency Range (MHz)	Impedance	Impedance Ratio	Insertion Loss (dB)	VSWR (:1)	RF Input Power Handling (W)
Z7550-BMBF+	DC-2300	50/75	1.5	0.6	1.6	2

Z7550-BMBF+





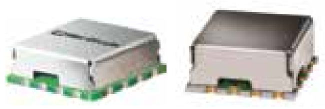


HIGHLIGHTS

- New surface mount VCOs with low phase noise
- Application note: Specifying VCOs for High Frequency Clock Circuits

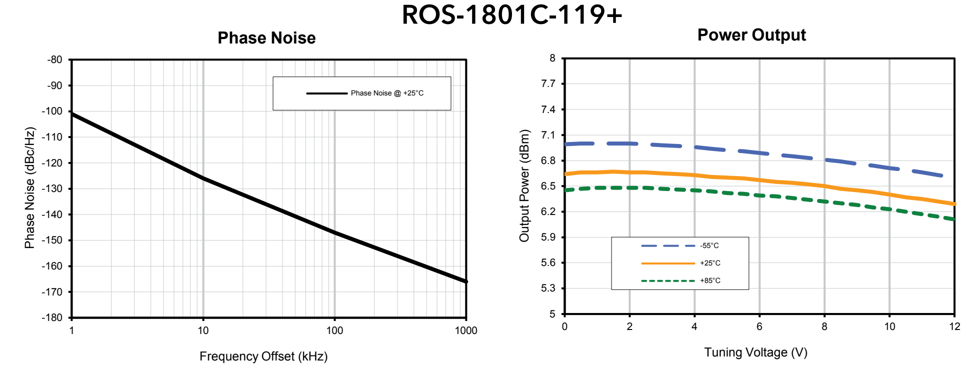
Surface Mount VCOs

- Low phase noise
- Good pushing and pulling
- Small size
- Robust design and construction

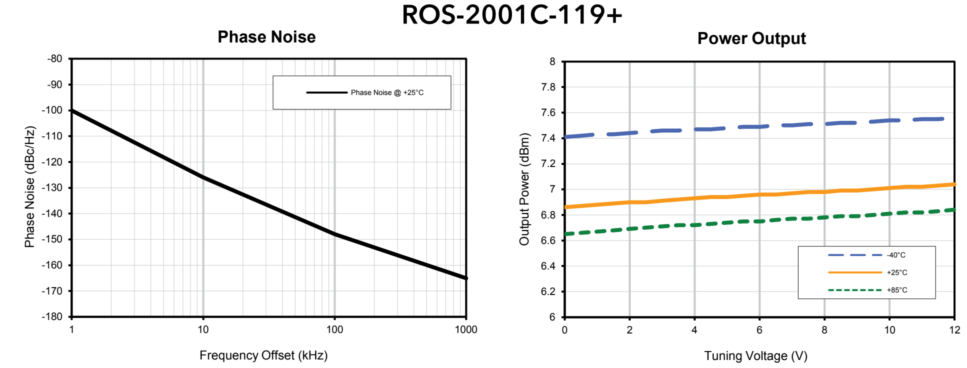


Model Number	Frequency Range (MHz)	Power Output (dBm)	Tuning Voltage (V)		Phase Noise dBc/Hz SSB at offset frequencies, kHz Typ				Pulling (MHz) pk-pk @ 12 dBr,	Pushing (MHz/V),	Tuning Sensi-tivity (MHz/V)	Harmonics (dBc)		3 dB Control BW (MHz),	DC Operating Power	
		Typ.	Min.	Max.	1	10	100	1000	Typ.	Typ.	Typ.	Typ.	Max.	Typ.	Vcc (volts)	Current (mA) Max.
ROS-1801C-119+	1800-1800	6	0.5	9.5	-101	-126	-147	-166	0.2	0.1	1.5	-16		50	8	37
ROS-2001C-119+	2000-2000	7	0.5	9.5	-100	-126	-148	-165	0.2	0.1	0.7	-16		50	8	38
ROS-5815C-119+	5685-5815	3.5	0.5	4.5	-74	-106	-129	-149	1.5	1.5	70-80	-17		100	5	32

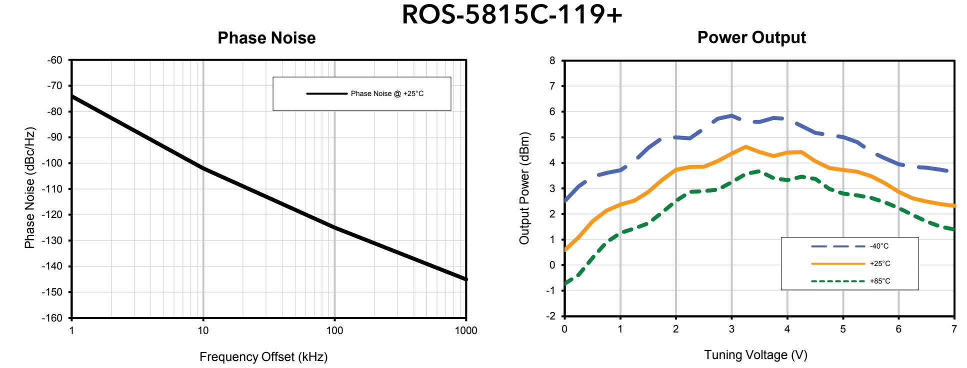
ROS-1801C-119+



ROS-2001C-119+



ROS-5815C-119+



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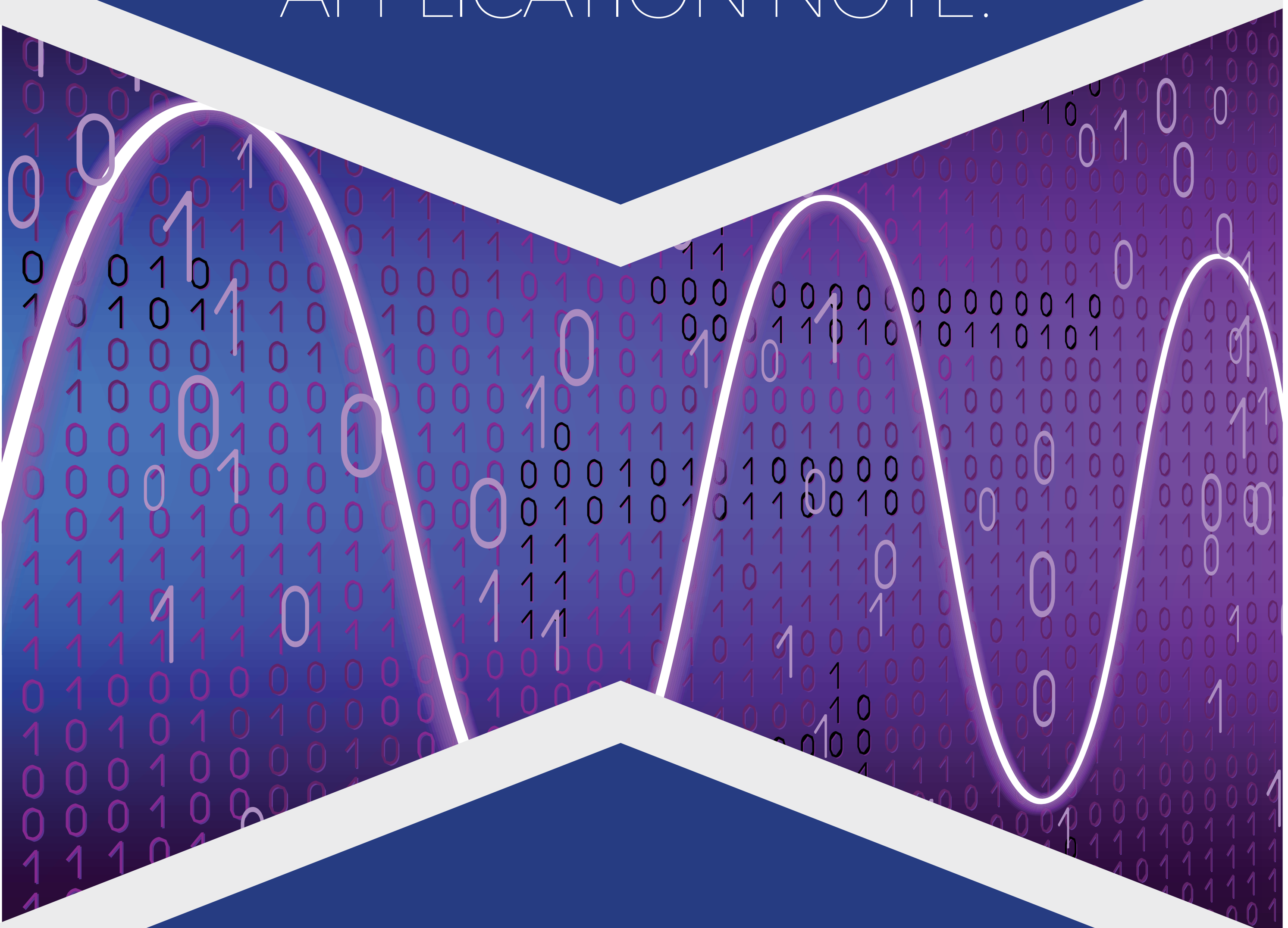

Specifying VCOs for Clock Timing Circuits

VCOs are capable of low noise and high stability with the convenience of tunable frequency for applications requiring reliable clock timing.

Timing is everything for many systems, especially for modern electronic systems with high-speed data converters and high-resolution sampling. A clock source is "the keeper of time" in these systems and system timing performance is very much dependent upon the performance of its clock source. For some system designers, a clock source automatically means a crystal oscillator, typically a single-frequency source. But some system designers, especially those faced with synchronizing systems at multiple clock frequencies, have learned to appreciate the flexibility of using voltage-controlled oscillators (VCOs) as clock sources.

VCOs can serve as clock timing circuits for wireless communications networks, video broadcast systems, and test equipment, essentially any systems requiring timing synchronization, for data processing, digital signal processing, or channeling of logic signals. VCOs support data-conversion circuits in analog-to-digital converters (ADCs), digital-to-analog converters (DACs), and logic circuits in need of reliable clock timing signals. These tunable, high-frequency oscillators are available from many different suppliers in many different formats, from chips to packaged devices, making the task of specifying a VCO for a clock timing application or even a traditional analog heterodyne receiver no simple task. Selecting a VCO for clock timing applications requires an understanding of VCO performance specifications and how they can be applied in the time-domain realm of clock timing circuits.

Working with clock timing circuits usually involves tight management of timing accuracy in the clock timing source. Errors in clock timing can result in poor digital system performance, causing lost or missing data. High-speed clock signals are usually characterized by fast rise and fall times, with an amplitude-versus-time plot showing a peak amplitude with very sharp edges (Fig.1). Sharper slopes leading to and trailing from the peak amplitude represent less noise and less timing errors. Clock signals that are narrower or wider than optimum limits are errors in clock timing caused by phase noise and can degrade system performance.

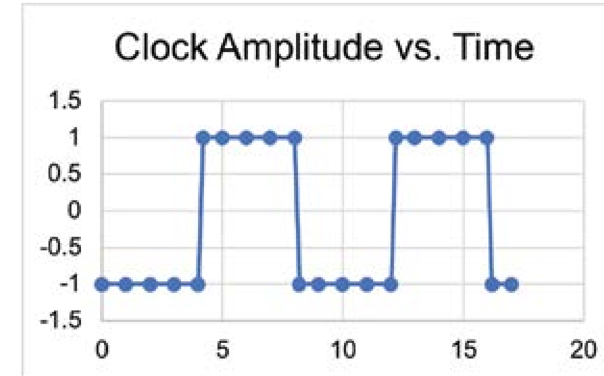

Figure 1: High-speed clocks require signals with sharp leading and trailing edges and sharp rise times to clearly define timing in system applications.

An ideal clock signal plot would show a signal trace with almost vertical, 90° rising and falling edges to the peak amplitude of the output signal. Unfortunately, real-world clock oscillators suffer some amount of noise due to signal power spread from the carrier to the sidebands as well as the generation of harmonics of the desired output frequency. Noise can also result from nonharmonic, spurious signal sources falling within the bandwidth of the oscillator. Additionally, energy spread from the carrier to the sidebands causes variations in signal frequency and phase and is measured as single-sideband (SSB) phase noise (Fig. 2). All these noise sources can cause timing errors in an oscillator that is used as a clock source.

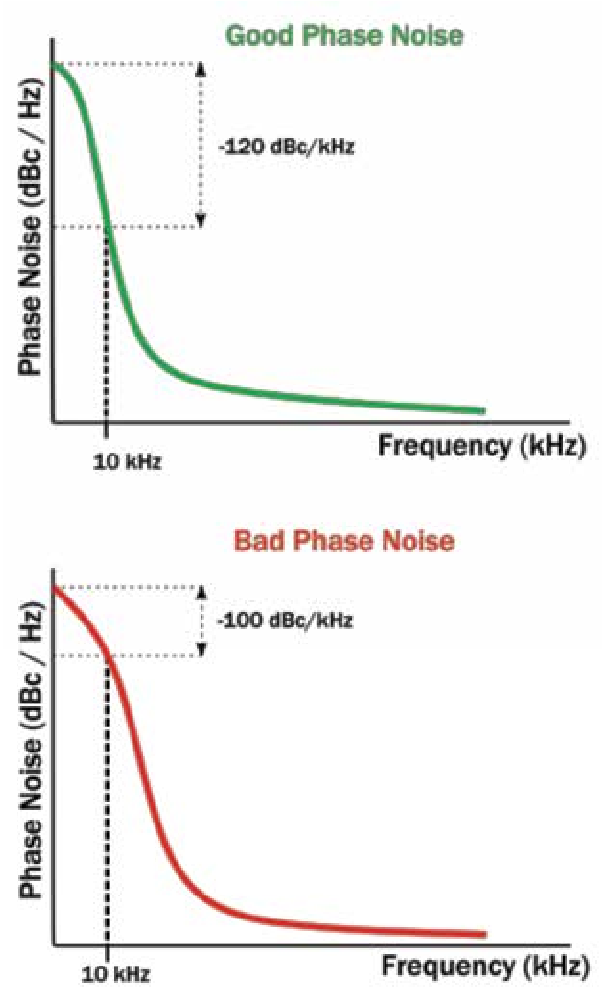

Figure 2: Oscillator phase noise is a measure of noise levels at different offset frequencies from the carrier.

While no ideal clock timing source may exist, good sources are available. Oscillator noise parameters of SSB phase noise, harmonic noise, and spurious noise provide a means to determine the usefulness of a given model as a clock timing source. VCOs provide output signals at a specified center frequency (fc) and modulation bandwidth around that center frequency. A VCO's tuning range is defined by a minimum and maximum frequency and by the tuning voltage that is applied to the oscillator to produce the frequencies within its tuning range.

Asynchronous clocking applications, such as video broadcast systems and Ethernet systems, typically employ many different clock oscillators serving as local timing reference sources for different components (such as ADCs, DACs, and FPGAs) within the system. For such applications requiring multiple clock signals, the frequencies of those clock signals will establish a minimum tuning range for a VCO used as a clock oscillator, perhaps with added bandwidth to allow for some amount of frequency tolerance within the system. The VCO's tuning step size should provide the frequency resolution (such as 1 kHz) required to produce the frequencies of the multiple timing signals. Commercial VCOs are available with both narrowband and wideband tuning ranges, although the tuning response must provide the frequency resolution required by a given application.

The frequency control of a VCO is also defined by its tuning speed, which is typically the time for an oscillator to settle within 90% of its final frequency after a change in tuning voltage has been applied. The tuning speed may also be described by a VCO's settling time, which is a function of modulation bandwidth (longer settling times for wider bandwidths).

Additional VCO frequency-tuning parameters to consider include:

- **post-tuning drift:** variations from a desired frequency within a specified time after a tuning voltage has been applied;
- **frequency pushing:** variations from a desired frequency due to changes in power-supply voltage, usually expressed as MHz/V; and
- **frequency pulling:** variations from a desired frequency as a result of impedance loads from other components within the same system, such as amplifiers and filters connected to the VCO.

For systems with multiple VCOs, pulling can cause frequency errors and timing differences between clock oscillators that can impact bit error rate (BER) and digital system performance.

Controlling Noise and Jitter

For high-speed clock timing circuits, clock timing oscillators should provide high stability, with the lowest levels of noise possible, including low SSB phase noise, harmonics, and spurious noise. All three forms of noise can degrade system-level performance when a VCO is used as a clock timing oscillator. In the frequency domain, SSB phase noise close to the carrier (such as offset 1 or 10 kHz from the carrier) is usually considered of most concern because it is often being mixed with the carrier as a local oscillator (LO) for receiver or transmitter frequency-conversion applications. In the time domain, where phase noise is referred to as "jitter," high noise levels at offsets further from the carrier are also of greater concern because they are an indication of large amounts of wideband noise. When phase noise is represented as jitter, it is the total integrated phase noise (noise at all offsets) that is considered for jitter conversions and noise far from the carrier can contribute to increased jitter. Especially for VCOs used as clock sources, noise far from the carrier can be thought of as degrading the rise and fall times or sharpness of a clock's pulse edges, resulting in timing errors.

Jitter refers to timing variations in the signal edges of an oscillator's clock signals when compared to perfectly timed clock signals (Fig. 3). The signal timing variations are caused by noise within a system and can be the result of the effects of changing operating temperatures, power-supply variations, changes in the impedance load conditions, semiconductor device noise, and interference from nearby circuits. When considering a VCO for clock timing applications, whether it be phase noise or jitter, the value should be as low as possible for the most precise timing results. In general, a VCO with acceptably low phase noise will also perform with very low jitter in clock timing circuits. The additional oscillator noise components from harmonic and spurious signals can also degrade the quality of oscillator spectral purity in the frequency domain and jitter performance in the time domain and should be kept at the lowest levels possible.

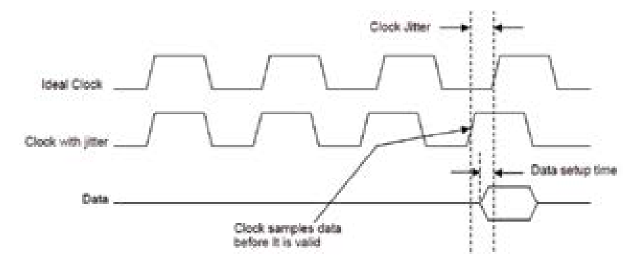

Figure 3: Jitter is a measure of timing variation in the edges of signal waveforms.

Comparing the phase-noise levels of different VCOs for clock timing applications is typically not a simple task since the phase noise occupies so many different sidebands around a carrier frequency (fc) of interest. Phase noise is typically at its highest levels close to the carrier, with noise levels dropping for offsets further from the carrier. The phase noise typically has three slopes, with the highest slope, for noise also known as flicker FM noise, close to the carrier. The middle slope region of phase noise is known as 1/f noise, with steadily decreasing noise further from the carrier. The region of phase noise furthest from the carrier, at the lowest levels of noise, is known as white noise or broadband noise. Because jitter equates to the total integrated phase noise of an oscillator, higher broadband phase noise contributes to higher jitter. High jitter causes errors in digital system sampling time, reduced signal-to-noise ratio (SNR) and missing or lost digital bits.

Measurements of phase noise are performed in one of the sidebands (<fc or >fc) within a 1-Hz bandwidth at various offsets from the carrier frequency. It is important that the noise levels being compared for different oscillators are for the same carrier frequency and offsets. Because the noise power is at frequencies lower or higher than the desired carrier, high phase noise results in some "detuning" of the carrier frequency, depending upon the sideband and the offset frequency. For clock timing applications, the SSB phase-noise levels across all offsets from the carrier are important, especially at offsets greater than 10 MHz (which are often not considered for analog applications). In short, lower levels of SSB phase noise equal low jitter in VCOs.

Connecting a VCO

Analog circuit designers have long applied VCOs' outputs to heterodyne receiver ports as LO signals, converting RF input signals to intermediate-frequency (IF) signals for processing. In the mixed-signal and digital circuit realms, components such as digital signal processors (DSPs), ADCs, and DACs provide clock input ports for timing and synchronization purposes. Signals for these clock inputs have traditionally been provided by lower-frequency clock oscillators. But as the speeds and frequencies of digital components continue to climb, VCOs appear as more likely candidates for clock timing sources because they provide the higher frequencies, lower phase noise, and outstanding stability needed for clock timing circuits. The impact of VCO performance on analog systems is well understood, and VCOs can be just as valuable as timing sources for digital systems.

Fortunately, VCO phase-noise plots and an oscillator's spectral purity (including harmonics and spurious noise) can be translated into jitter for clock timing applications using equations available in the literature or a jitter mask which is imposed over a VCO's phase-noise plot to identify noise at offset frequencies of interest. The phase noise may not be critical at all offsets; for example, noise at offsets from 12 kHz to 20 MHz has traditionally been of main concern for optical communications applications such as synchronous optical network (SONET) communications systems. In general, a jitter mask (Fig. 4) can be a useful tool for identifying design limits, such as the maximum SSB phase noise levels corresponding to required jitter design limits in the time domain.

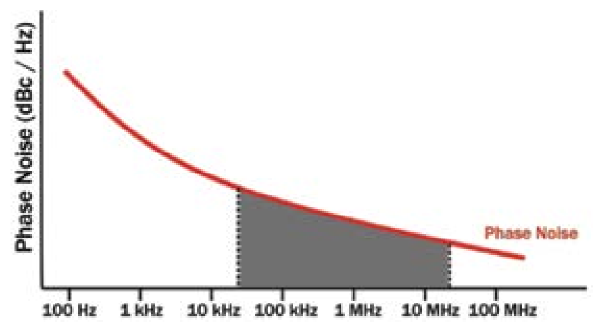

Figure 4: A jitter mask makes it possible to evaluate a VCO's frequency-domain spectral purity characteristics relative to the jitter performance in the time domain.

Sizing Up Specs

What type of VCO performance levels are needed for providing dependable clock timing in real-world applications? For a sampling of VCOs developed for clock timing applications, see the table. Model 4608CH-2+ is a fixed-frequency oscillator developed to provide a fixed timing signal at 4608 MHz for cable television (CATV) systems. It is housed in a compact surface-mount package (Fig. 5) for operating temperatures from -5 to +95°C.

At less than one-half the frequency, model ROS-1801C-1+ provides clock timing signals at 1800 MHz as a drop-in replacement for fixed-frequency integrated-circuit (IC) VCOs in many test equipment and system applications. It provides as much as +8 dBm output power and typically +6 dBm output power with typical tuning sensitivity of 1.5 MHz/V for a tuning-voltage range of 0.5 to 9.5 V.

Figure 5: Model ROS-4608CH-2+ is a surface-mount VCO with fixed-frequency output at 4608 MHz with typical tuning sensitivity of 6 MHz/V for a control voltage range of 0.9 to 4.35V

At 2000 MHz, model ROS-2000C-6+ is a VCO well suited for clock timing applications in emerging Fifth Generation (5G) clock timing applications. The RoHS-compliant source is also housed in a compact surface-mount package, with very little drift across a wide operating temperature range of -40 to +85°C. All three VCOs feature low phase noise and outstanding frequency stability to serve as clock timing sources.

In short, electronic systems continue to move higher in frequency and speed, with growing numbers of users relying on those systems for communications, transportation, even health care. To keep users and their systems connected, timing is everything, and electronic timing depends on a high-quality clock source, often more than one. For higher system frequencies, low-noise VCOs provide the timing accuracy needed to maintain many systems well into the future.

Note: For more on VCO performance parameters, refer to "Glossary of VCO Terms" https://www.minicircuits.com/appdoc/AN95-003.html on minicircuits.com. For more on VCO testing, refer to "Mini-Circuits® VCO Test Methods." https://www.minicircuits.com/appdoc/VCO15-15.html

VCOs

RESEARCH & EDUCATION

HIGHLIGHTS

▶ Mini-Circuits has expanded our partnership with Vayyar to bring the industry more innovative solutions for research and education in the RF/Microwave field. Our UVNA-63 DIY vector network analyzer kit gave the academic community a hands-on learning tool to help student engineers bridge the gap between classroom theory and real-world measurement in the lab. Now, we're pleased to introduce the VTRIG-74, a compact, cost-effective evaluation kit for 3D millimeter wave imaging and sensing.

VTRIG-74 | 3D Millilmeter Wave Imaging Kit

The VTRIG-74 is a revolutionary tool incorporating Vayyar's highly integrated RFIC technology and radar IP into a compact evaluation kit. This kit enables researchers around the world to explore and realize millimeter wave imaging and sensing applications without the cost and overhead that would otherwise be associated with developing the required hardware.

- 20 Tx and 20 Rx on-board antennas that can be configured to transmit and receive signals anywhere within the 62 to 69 GHz range.
- Provides unmatched flexibility for hardware developers and researchers with three performance-optimized transmit profiles and direct access to the Tx/Rx pair phasors for each swept frequency point. Impeccably accurate calculations. Operates on Windows. Compatible with Python or Matlab®.
- The High resolution profile uses 20 Tx and 20 Rx antennas ideal for high-resolution 3D imaging.
- Medium and fast scan profiles using 10 or 4 Tx antennas are ideal for applications such as 2D imaging or object tracking, which don't require high angular resolution.

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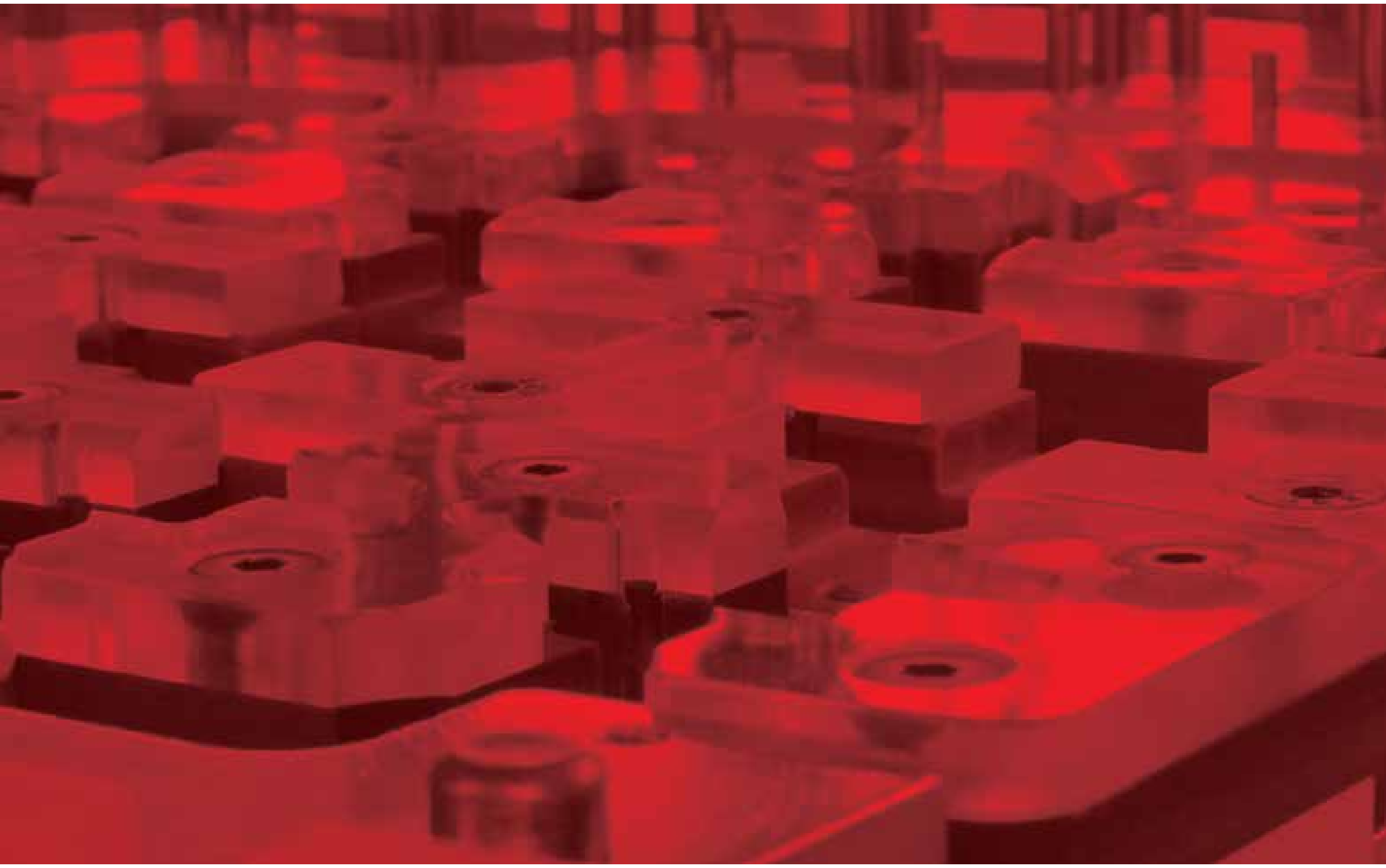

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