APPLICATION NOTE

Performance of Circulators Under Peak and Average Power Conditions

This Application Note describes the power testing of Skyworks circulators. A number of circulators for different frequency bands were selected. Due to the limited availability of RF pulse power sources that can supply peak power at the maximum rated duty cycle, the performance of each circulator was evaluated using three separate test configurations using rated average power and peak power:

1. Insertion loss measured with a 20 μs peak power pulse @ 1 percent duty cycle.
2. Insertion loss measured with a 100 μs peak power pulse @ 10 percent duty cycle.
3. Insertion loss measured under continuous power condtions.

The peak pulse power source available supplies 2 kW of peak power for 20 μs at a 1 percent duty cycle (test setup A – see Figure 2). An additional setup that provides longer pulses (100 μs) at a higher duty cycle (10 percent) at up to 1800 W was used to test two parts at 1030 MHz (test setup B – see Figure 4). Finally, circulators were measured with a continuous input power of 200 W (test setup C – see Figure 6).

Test Fixture

The circulators are soldered into a standard test fixture. The fixture is made from aluminum for better heat dissipation. Typical SMA connectors are fitted to the edge of the fixture. The tabs on the circulator are soldered on to 50 Ω traces on three substrates. When necessary during the high power testing, the test fixture is mounted on a heat sink to further improve heat dissipation.

The test fixture and heatsink are illustrated in Figure 1.

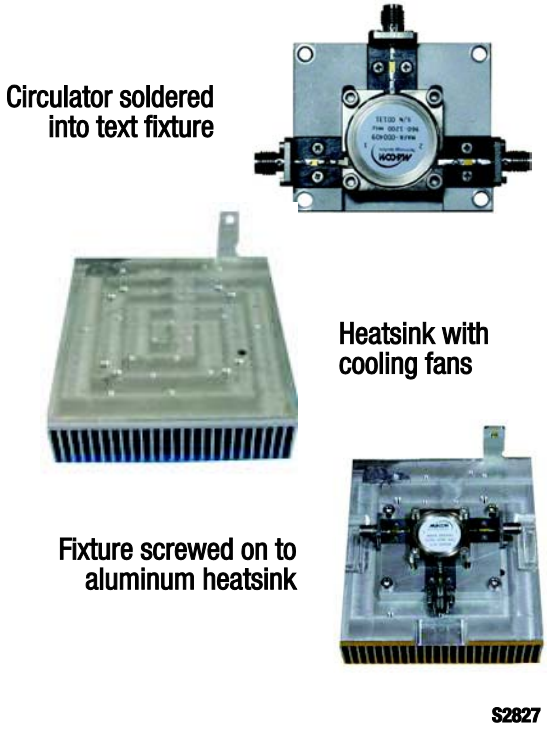

Figure 1.Test Fixture and Heatsink

Test Setup A: Insertion Loss Measured with a 20 μs Peak Power Pulse at 1% Duty Cycle

The process flow for this test is illustrated in Figure 2. The pulse power source is configured to supply a short pulse (20 μs) at various power levels up to 2 kW and at a 1 percent duty cycle.

Using directional couplers and attenuators, the input and output power is measured on a peak power meter. The losses between the power sensors and the DUT input and output are measured on a network analyzer and used to input the offsets used for the power meter. The peak power meter is configured to display the difference between both input and output peak power.

A calibration fixture with the same track lengths/connectors used on the test fixture is inserted in place of the DUT and a series of insertion loss measurements are made taken at the various power levels. The DUT and fixture are inserted into the test setup and another set of insertion loss measurements taken. The calibration fixture losses are subtracted to give the actual DUT insertion loss. This is repeated at various frequencies and across a number of different components in various frequency bands.

Test setup A is illustrated in Figure 3. The hardware used for test setup A is provided in Table 1. The results of insertion loss measurements are listed in Table 2.

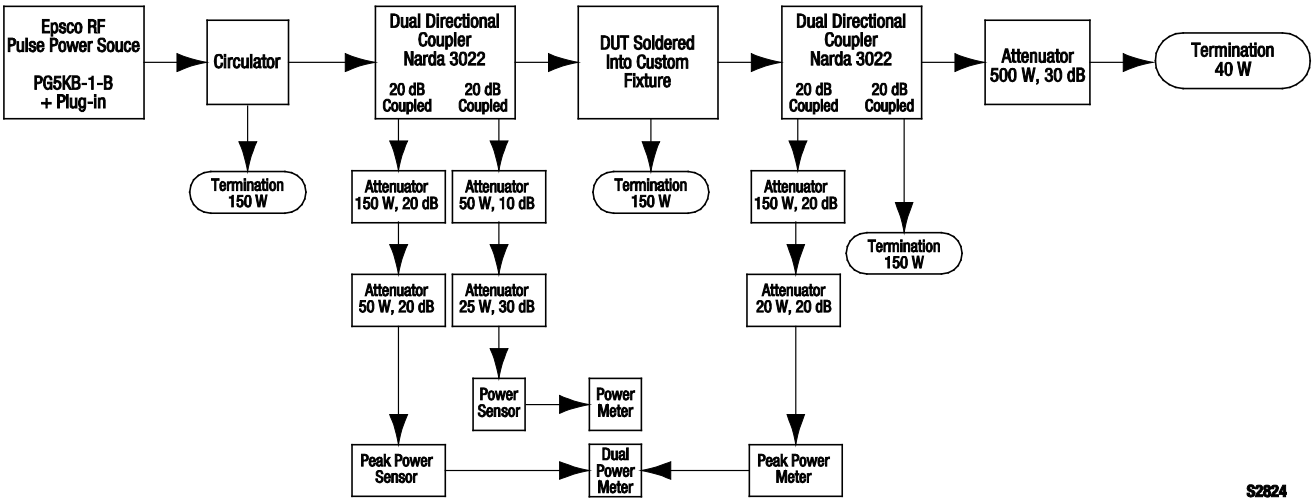

Figure 2. Test Setup A Process

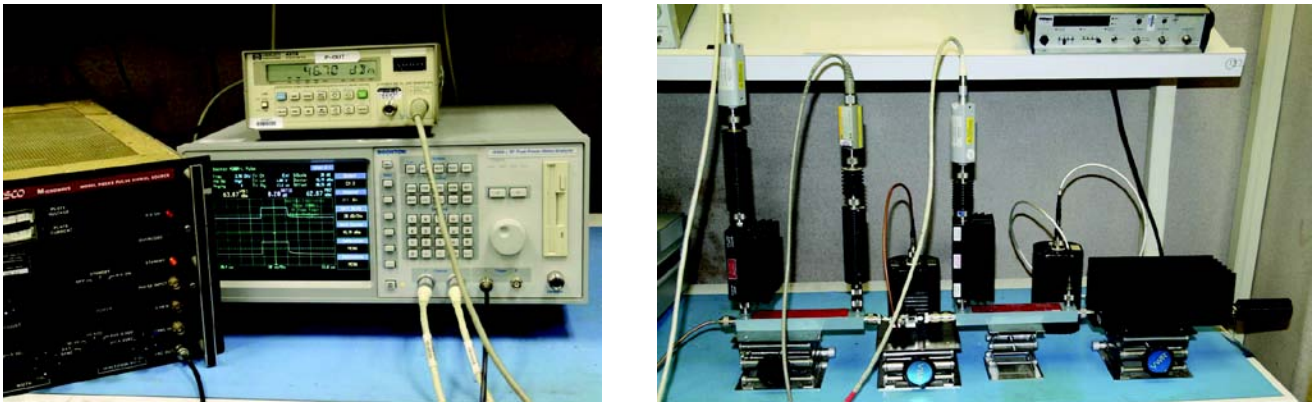

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Figure 3. Test Setup A

Table 1. Hardware for Test Setup A

Description	Manufacturer	Model Number	Quantity
High power RF pulse signal source mainframe	Lucas Epsco	PG5KB	1
950 to 1220 MHz, 5 kW peak, 0.3% duty cycle RF plug-in	Lucas Epsco	5234H	1
1225 to 1535 MHz, 5 kW peak, 0.3% duty cycle RF plug-in	Lucas Epsco	5235H	1
2700 to 3100 MHz, 4 kW peak, 0.3% duty cycle RF plug-in	Lucas Epsco	5239H	1
RF peak power meter analyzer	Boonton	4500-L	1
Peak power sensor, 500 MHz to 18.0 GHz, –40 to +20 dBm	Boonton	56518	2
Power meter	Agilent	437B	1
Power sensor, 10 MHz to 18 GHz, –30 to +20 dBm	Agilent	8481A	1
Test fixtures for circulators	Skyworks	–	2
Dual directional coupler, 500 W average, 10 kW peak	Narda	3022	2
Attenuator, 10 dB, 50 W average, 2 kW peak	Narda	765-10	1
Attenuator, 20 dB, 50 W average, 2 kW peak	Narda	765-20	1
Attenuator, 20 dB, 150 W average, 5 kW peak	Weinschel	49-20-34	2
Attenuator, 20 dB, 20 W average, 1 kW peak	Narda	768-20	1
Attenuator, 30 dB, 25 W average, 1 kW peak	Weinschel	33-30-33	1
Attenuator, 30 dB, 500 W average, 1 kW peak	Weinschel	8543-30-33	1
Termination, 150 W average	Termaline	8166	3
Termination, 40 W, DC to 12.4 GHz	Narda	376BNM	1

Table 2. Test Setup A: Insertion Loss Measurements

Part Number	Frequency (MHz)	Insertion Loss (dB)			
		200 W	800 W	1400 W	2000 W
MAFR-000409-000001	1090	0.27	0.32	0.33	0.35
MAFR-000493-000001	1090	0.17	0.20	0.22	0.22
MAFR-000399-000001	1450	0.17	0.22	0.24	0.25
MAFR-000403-000001	3100	0.14	0.22	0.22	0.23
MAFR-000514-000001	3100	0.11	0.14	0.15	0.16

Test Setup B: Insertion Loss Measured with a 100 μs Peak Power Pulse at 10% Duty Cycle

The process flow for this test is illustrated in Figure 4. The pulse power source is configured to supply a short pulse (100 μs) at various power levels up to 2 kW and at a 10 percent duty cycle.

A pair of pulsed power modules is combined to achieve the high peak power required. The modules are driven by a single pulsed power transistor using a power divider.

The drive signal for the transistor is generated by a standard signal generator and power amplifier. The overall output power is controlled by adjusting the signal generator output power level. This setup only operated at 1030 MHz.

Under peak power conditions, the circulators are visually monitored for voltage breakdown (arcing) between the center conductor and ground.

Test setup B is illustrated in Figure 5. The hardware used for test setup B is provided in Table 3. The results of insertion loss measurements are listed in Table 4.

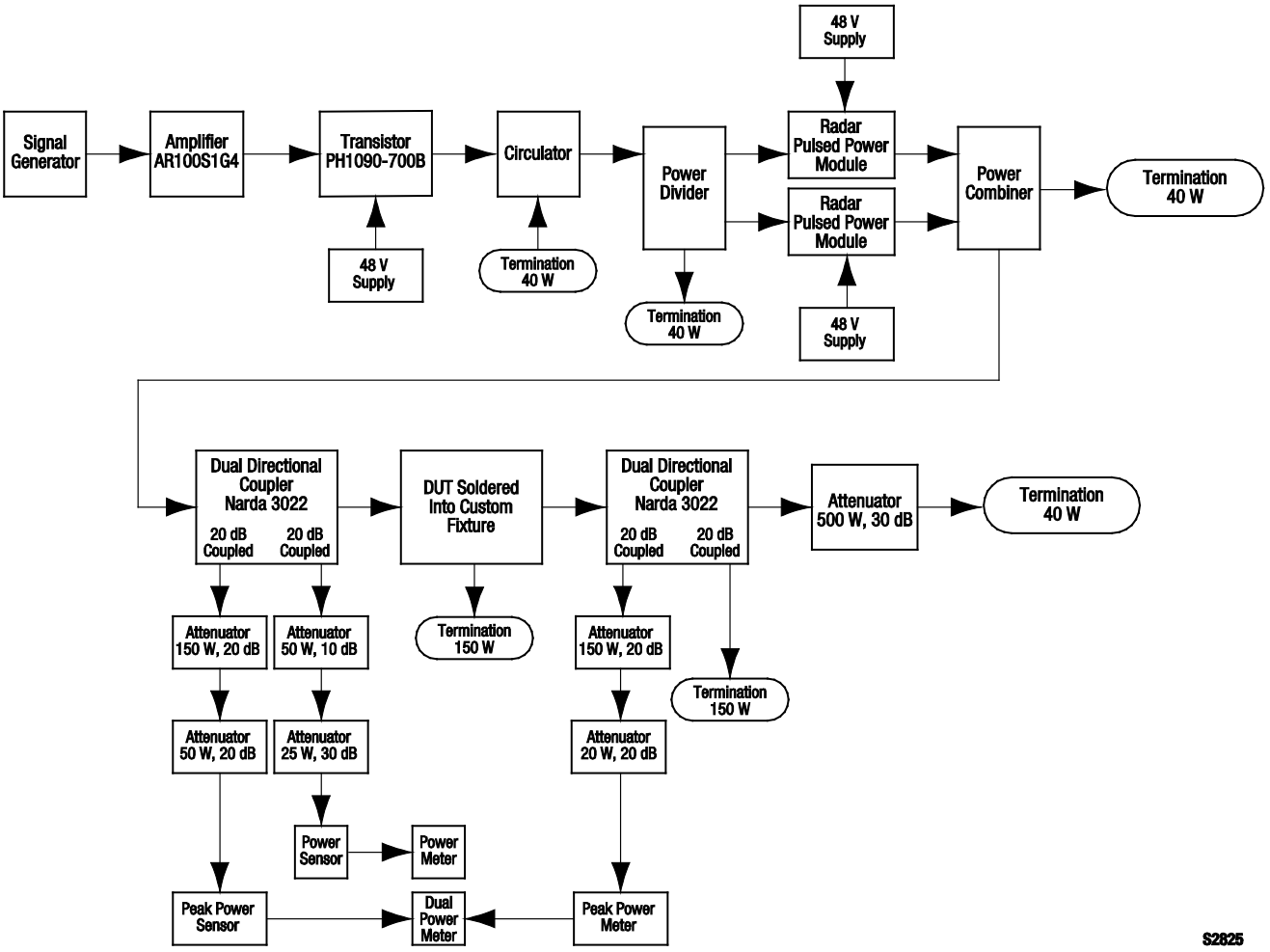
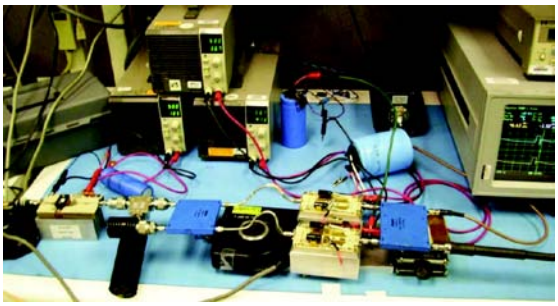
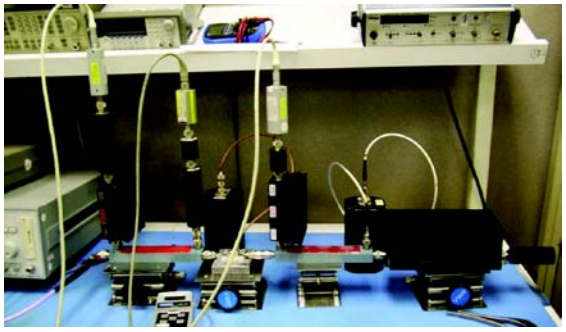


Figure 4. Test Setup B Process

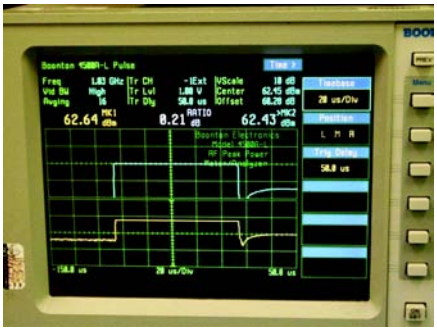
Power Amplifier



Radar Pulsed Power Modules



DUT and Peak Power Sensor Setup



Peak Power Meter Display

Figure 5. Test Setup B

Table 3. Hardware for Test Setup B

Description	Manufacturer	Model Number	Quantity
ESG-AP series RF signal generator, 4 GHz	Agilent	E4426B	1
Amplifier, 100 W, 0.8 to 4.2 GHz	Amplifier Research	AR100S1G4	1
Power supply, 60 V, 12 A	Kikisui	PAK60-12A	3
Hybrid coupler, 3 dB, 90 deg., 0.5 to 2.0 GHz	Anaren	1A0024-3	1
Pulsed power transistor, 32 ms, 700 W, 2% duty cycle	M/A-COM	PH1090-700B	1
Radar pulsed power module, 1030 MHz, 1 kW	M/A-COM	custom design	2
Hybrid coupler, 3 dB	Anaren	1A0024-3	1
RF peak power meter analyzer	Boonton	4500-L	1
Peak power sensor, 500 MHz to 18.0 GHz, –40 to +20 dBm	Boonton	56518	2
Power meter	Agilent	437B	1
Power sensor, 10 MHz to 18 GHz, –30 to +20 dBm	Agilent	8481A	1
Test fixtures for circulators	Skyworks	–	2
Dual directional coupler, 500 W average, 10 kW peak	Narda	3022	2
Attenuator, 10 dB, 50 W average, 2 kW peak	Narda	765-10	1
Attenuator, 20 dB, 50 W average, 2 kW peak	Narda	765-20	1
Attenuator, 20 dB, 150 W average, 5 kW peak	Weinschel	49-20-34	2
Attenuator, 20 dB, 20 W average, 1 kW peak	Narda	768-20	1
Attenuator, 30 dB, 25 W average, 1 kW peak	Weinschel	33-30-33	1
Attenuator, 30 dB, 500 W average, 1 kW peak	Weinschel	8543-30-33	1
Termination, 150 W average	Termaline	8166	4
Termination, 40 W, DC to 12.4 GHz	Narda	376BNM	2
Termination, 20 W, DC to 12.4 GHz	Narda	374BNM	1

Table 4. Test Setup B: Insertion Loss Measurements

Part Number	Frequency (MHz)	Insertion Loss (dB)			
		200 W	800 W	1400 W	1840 W
MAFR-000409-000001	1030	0.20	0.19	0.22	0.22
MAFR-000493-000001	1030	0.14	0.14	0.15	0.16

Test Setup C: Insertion Loss Measured Under Continuous Power Conditions

The process flow for this test is illustrated in Figure 6. The circulators are operated at 200 W of continuous power for 30 minutes. Insertion loss is measured using a power meter and sensors. The temperature of the circulator is monitored (maximum temperature is 75 °C).

Test setup C is illustrated in Figure 7. The hardware used for test setup C is provided in Table 5. The results of insertion loss measurements are listed in Table 6.

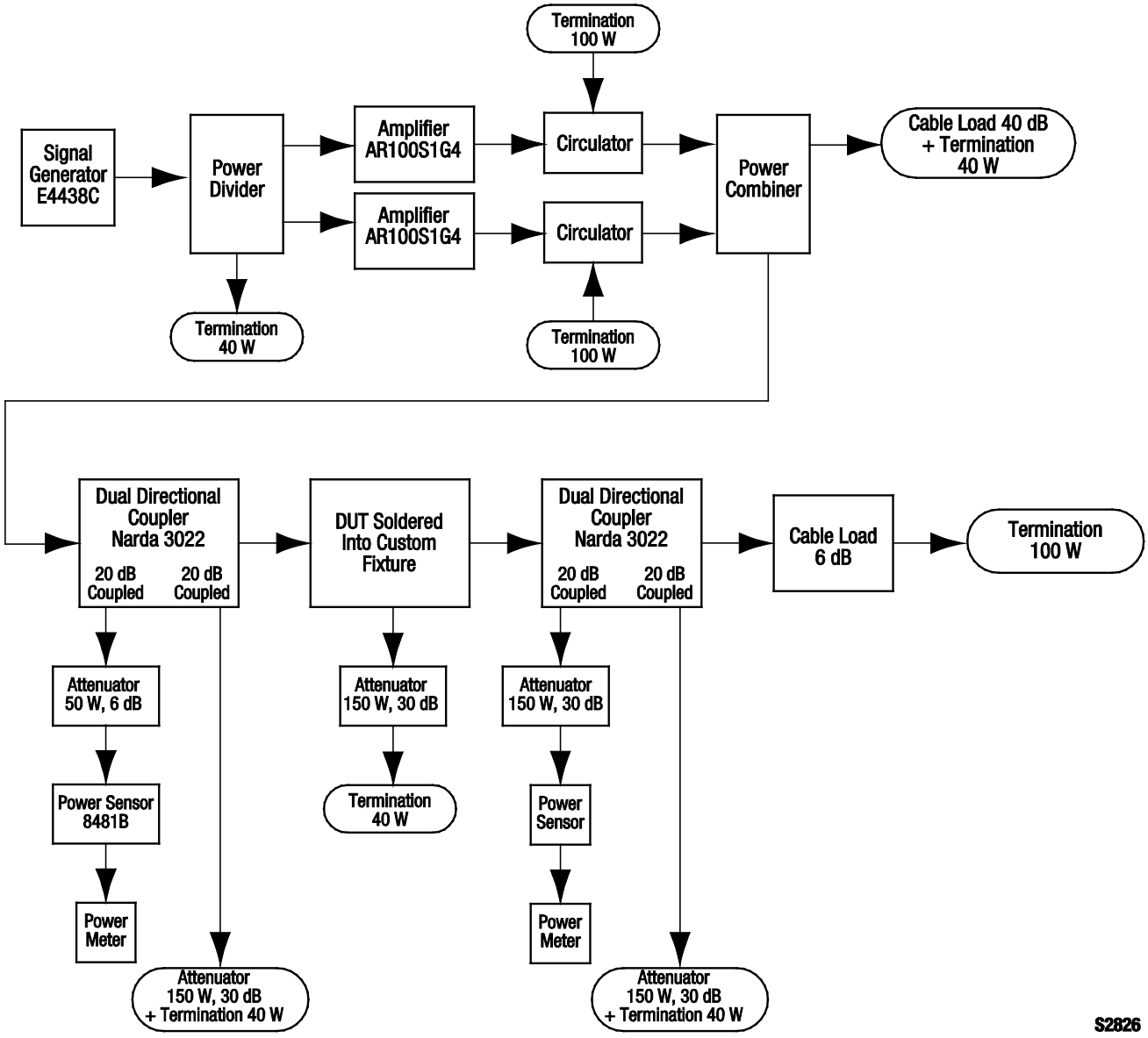


Figure 6. Test Setup C Process

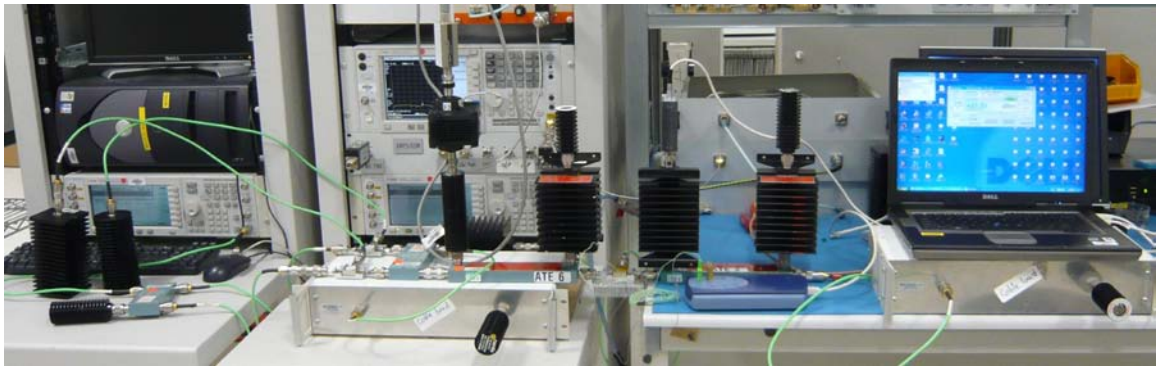


Figure 7. Test Setup C

Table 5. Hardware for Test Setup C

Description	Manufacturer	Model Number	Quantity
ESG vector signal generator	Agilent	E4438C	1
RF amplifier, 120 W, 0.8 to 3.0 GHz	Amplifier Research	AR100S1G3	2
EPM series power meter	Agilent	E4418B	1
Power sensor, 1 mW to 25 W, 10 MHz to 18 GHz	Agilent	8481B	2
Attenuator, 6 dB, 50 W	Narda	765-6	2
Hybrid coupler, 3 dB, 90 deg.	Narda	3032	2
Dual directional coupler, 500 W average, 10 kW peak	Narda	3022	2
High power attenuator, 150 W average, 3 kW peak	Narda	769-30	4
Termination, 100 W average, 5 kW peak	MECA	490-2	2
Cable load, 40 dB	Skyworks	custom design	2
Termination, 40 W, DC to 12.4 GHz	Narda	376BNM	5
Custom test fixture to solder in the DUT	M/A-COM	custom design	3
Circulators, single junction	M/A-COM	custom design	3
Termination, 40 W, DC to 12.4 GHz	Narda	376BNM	2
Termination, 20 W, DC to 12.4 GHz	Narda	374BNM	1

Table 6. Test Setup C: Insertion Loss Measurements

Part Number	Frequency (MHz)	Insertion Loss (dB)	
		1 mW	200 W
MAFR-000409-000001	1030	0.24	0.27
MAFR-000493-000001	1030	0.16	0.22
MAFR-000399-000001	1450	0.18	0.16

Conclusions

Power testing demonstrates the capability of Skyworks circulators to handle both the rated peak pulse power and average power without degradation of performance. There is a marginal increase in insertion loss at higher power levels, but it is of a similar order of magnitude to the accuracy of the measurement system.

There is also good correlation between the values measured and the small signal insertion loss measured on a network analyzer.

All of the circulators that were measured were within specification under both the average and peak pulse power conditions.

At peak power levels, no voltage breakdown (arcing) was detected between the center conductor and ground.