Maximum Peak Power of Ferrite Junctions Application Note

Brief Information on Arcing and Breakdown Voltages:

The phenomenon of arcing is a complex mechanism[1,2]. It depends on:

1. The breakdown voltage of the dielectric material between the electrodes,
2. The surface geometry of the electrodes, and
3. The applied waveforms.

Generally speaking, the threshold for arcing is lower with the following conditions:

1. Lower breakdown voltages, and/or
2. Sharp edges (rough surfaces).

Since the applied waveform is a function of signal frequency, pulse shape/duration, and circuit matching conditions, it is typical to consider the worst-case condition or to use a stochastic approach to derive the margin/de-rating factor.

The breakdown voltage (if air is the dielectric) is primarily a function of (p • d) (the product of air pressure and distance between the electrodes)[1]. Empirical equations attached at the end of this note can be used to estimate the minimum breakdown voltages.

When solid materials are used between the electrodes, the breakdown voltage is usually elevated. But if there are voids in the dielectric filling, the internal breakdowns (across the voids) occur at voltages lower than the intrinsic breakdown voltage of the dielectric. If such internal breakdowns are allowed to repeat, the dielectric will deteriorate by the combination of the thermal and chemical effects associated with the discharges. This eventually leads to

The optimal way of characterizing the maximum input power (without arcing) of circulators/isolators is to use power amplifiers (at operating frequency) as the input. With proper matching, the device under test can be checked for arcing. If such setup is not available, the minimum power to cause arcing can be explored with a meter capable of high voltage output. The test is typically performed with DC/60Hz test signals, the breakdown voltage observed can be used to derive the RF power that will cause arcing, using the following equation:

$$P = V_{breakdown}^2 / Z_{system}.$$

In other words, if a 50Ω device can withstand 200 Volts (peak-to-peak) before breakdown, the maximum power without arcing is: 200*200/50 = 800 (Watts).

SETUP used at M/A-COM:

The High Potential Meter, or “HiPot” as they are commonly called, uses a variable transformer to increase the output voltage to Kilo-Volts range. The meter used at M/A-COM (“HyPot Junior”, Model # 4045 by Associated Research Inc.) has adjustable (AC/DC) outputs ranging from 0V up to 5KV. When arcing is encountered, popping/cracking noise can be heard. Most of time, the arc itself can be easily observed, especially in a dark room. The light on the panel of the meter labeled “BREAKDOWN” will light-up. If the sustained current is greater than 1 mA, another light labeled “LEAKAGE” will also be lit-up. The tester has a current-limiter (5 mA) so the power output is not large enough to damage the devices under test(DUTs). Fig. 1 depicts the typical setup.

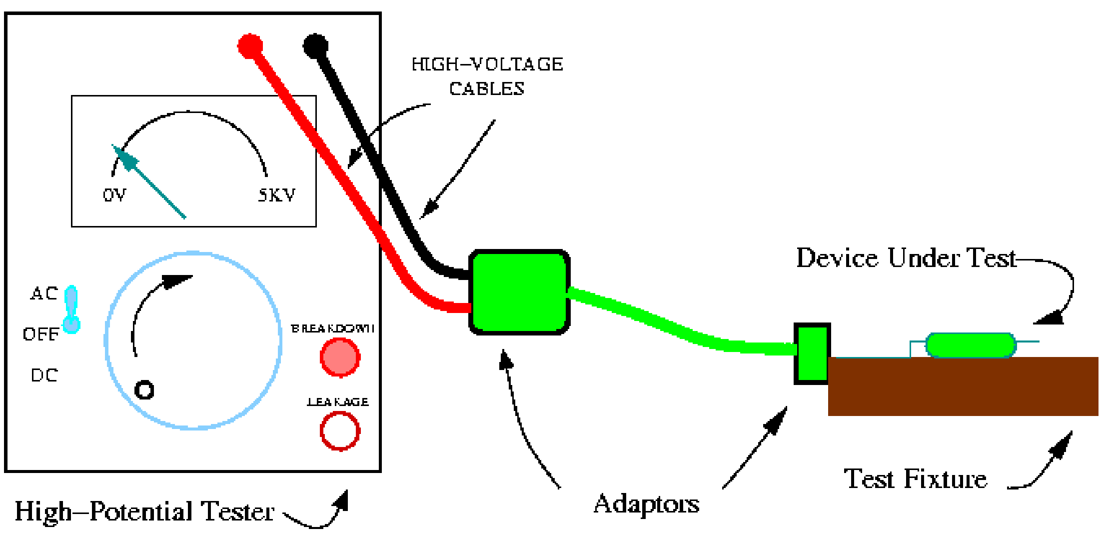

Figure 1: High Potential Meter Setup Diagram.

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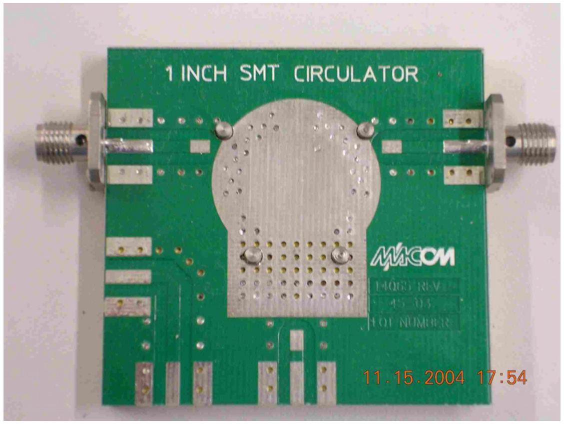

Figure 2:
Test Fixture for mounting the Isolators.

Because this is a DC/60Hz test, the DUT must present an open circuit at DC. The isolators have to be prepared by removing the pins from the chip-resistors. The DUT is then soldered onto a test fixture (M/A-COM part # 14064 Rev-). Please see Fig. 2 for the close-up photo of the fixture.

The measurements started with characterizing the breakdown voltage of the test-fixture without any DUT. This is the upper limit of the test setup. The minimum breakdown voltage recorded is about 1500 V. Arcing can be observed between the microstrip line and the ground plane.

Several isolators were tested with this setup. The results are tabularized below.

M/A-COM Part Number	Minimum Breakdown Voltage	Location of Arcing Observed	Note
MAFRIN0425 (isolated tab unsoldered).	1450 V	Center Conductor (Port 3) ↕ Lower Ground Plane	Single-Ferrite Device (Fig. 3).
MAFRIN0377 (isolated tab unsoldered)	950 V	Center Conductor (Port 3) ↕ Upper Ground Plane	24 mil Ferrite. Upper ground plane sagging by ~ 12 mil. (Fig. 4)
MAFRIN0360 (isolated tab unsoldered)	350V	Center Conductor (resonator) ↕ Wall of Housing Can	30 mil thick Ferrite. Resonator Ø.770 mil Can Inside Ø.803 mil
MAFRIN0160 (isolated tab lifted)	400 V	Center Conductor (resonator) ↕ Wall of Housing Can	30 mil thick Ferrite. Resonator Ø.770 mil Can Inside Ø.803 mil (Figs. 5a & 5b)

Table 1:
Breakdown voltage tests performed on M/A-COM's isolators.
(Test conditions: T = 25°C. Pressure = 1 Atm.(760 Torr), Humidity 40% - 70%)

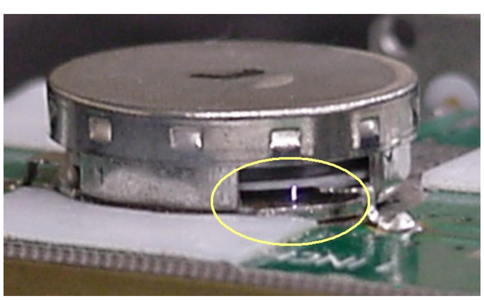

Figure 3:
Arcing between Isolated Port Tab (lifted) and the Lower Ground Plane (MAFRIN0425).

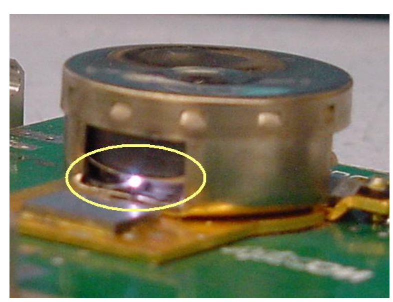

Figure 4:
Arcing between Isolated Port Tab (lifted) and the Upper Ground Plane (MAFRIN0377).

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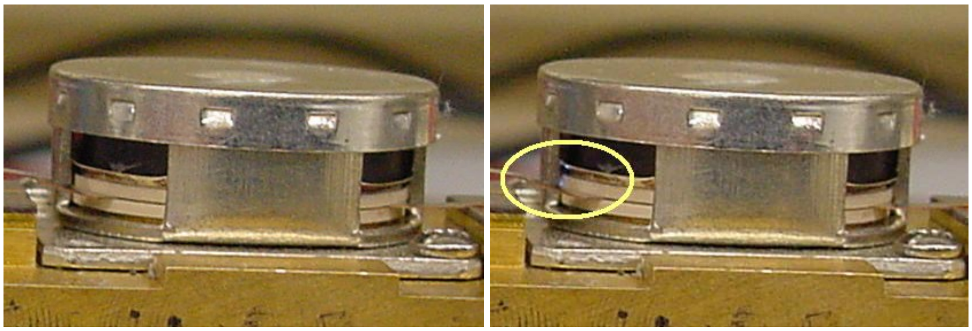

Figures 5a (No Arcing) & 5b:
Arcing between Resonator and the Housing Wall (MAFRIN0160).

The cases above show that the minimum voltage to cause arcing is about 350V. Or input power of 2450 Watts in a 50Ω system. This represents the "worst case" for possible arcing conditions among M/A-COM's circulator/isolator products. Please be advised this is for peak-power into a well-matched device. Any reflection and/or pulsing will further reduce this number. The reflected power in CW cases should cause thermal problems (e.g. blown-out terminations) well before arcing. For pulses, the peak-power, not the average power, should be used to determine the arcing threshold. In multi-carrier systems, determination of breakdown voltage becomes a stochastic problem. A derating factor (whose value could be -3dB to -14dB, depends on the number of carriers) should be used (see [3] for detail) to decide the threshold.

SUMMARY:

M/A-COM's Circulator/Isolator products' peak powers are specified according to the tests described above. The standard one-inch parts are rated at 2 Kilo-Watt peak power. The maximum average power of typical M/A-COM Circulators/Isolators (200 Watts) are specified with this number with a 10dB margin. Parts with larger packages have higher arcing thresholds. Please contact M/A-COM on specific parts or for further information.

EMPERICAL EQUATIONS for GASOUS BREAKDOWNS:

$$V_{Breakdown} = B \cdot p \cdot d / (C + \ln(p \cdot d));$$
$$\text{where } C = \ln(A / \ln(1 + 1/\gamma)).$$

The values of A, B, γ are obtained from experiments. See [4] for more details. For air:
A = 15, B = 365, and g = 0.01.
P is pressure in Torr (mm Hγ); d is distance (cm).

According to Townsend's discharge mechanism, the pressure should really be replaced by (gas) particle density. So the breakdown voltage is also a weak function of temperature (PV=nRT). At 100°C, the breakdown threshold maybe de-rated by 20% from these (room temperature) values. It must also be noted that drier environment leads to lower breakdown voltages.

[1] "Ionization and breakdown in gases" *F. Llewellyn-Jones*; Methuen & Co. Ltd., London, 1966, 2nd ed.
[2] "Theoretical modelling of the development of the positive spark in long gaps" *A. Bondiou* and *I. Gallimbert ;* J. Physics. D: Applied Physics, Volume 27, p. 1252-1266.
[3] "Multi-carrier microwave breakdown in air-filled components" *U. Jordan; T. Olsson; V.E. Semenov; V. Anderson;* and *V. Lisak;* Microwave Symposium Digest, 2001 IEEE MTT-S International , Volume: 3 , 20-25 May 2001 Pages:2223 - 2226 vol. 3.
[4] "Spark Discharge" *E. M. Bazelyan* and *Y. P. Raizer*; CRC PRESS LLC. FL. U.S.A. 1998.

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