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## Electrical Discharge Machining of Type-N(f) Microwave Connectors

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## **Electrical Discharge Machining of Type-N(f) Microwave Connectors**

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### **Abstract**

A particular out-of-specification mechanical dimension on Type-N(f) [Type-N(female)] microwave connectors sometimes disqualifies otherwise perfectly acceptable microwave devices from being used in calibration systems. The Miniature Machining Group at Sandia National Laboratories applied a technique called Electrical Discharge Machining (EDM) to quickly and economically machine these devices without disassembly. In so doing, they facilitated the use of existing components without the need to purchase new devices. The technique also improves an uncertainty of calibration known as Mismatch Uncertainty by optimizing the reflection coefficient of the calibration test port. This effects a reduction in overall calibration uncertainties.

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## **Acknowledgment**

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# Electrical Discharge Machining of Type-N(f) Microwave Connectors

## Introduction

The electrical performance of microwave devices fitted with Type-N(f) connectors is improved by utilizing an unconventional technique called Electrical Discharge Machining (EDM). EDM allows dimensionally "out-of-spec" connectors on otherwise perfectly acceptable microwave devices to be machined to meet modern specifications *without* disassembly. The process is carried out quickly and economically. By bringing mechanical dimensions up to modern specifications—a reduction in the reflection coefficient of the connector is achieved. This is especially important when the connector serves as the test port of a calibration system. A calibration uncertainty—Mismatch Uncertainty—is reduced when test port mechanical dimensions are optimized.

This report discusses the need to bring "out-of-spec" Type-N(f) microwave connectors up to modern specifications. It describes the EDM process in general, and how it is applied to this specific application.

The information contained in this report should be of value to metrologists and technicians needing to improve the mechanical dimensions, and thus the electrical performance of Type-N(f) microwave connectors.

## Background

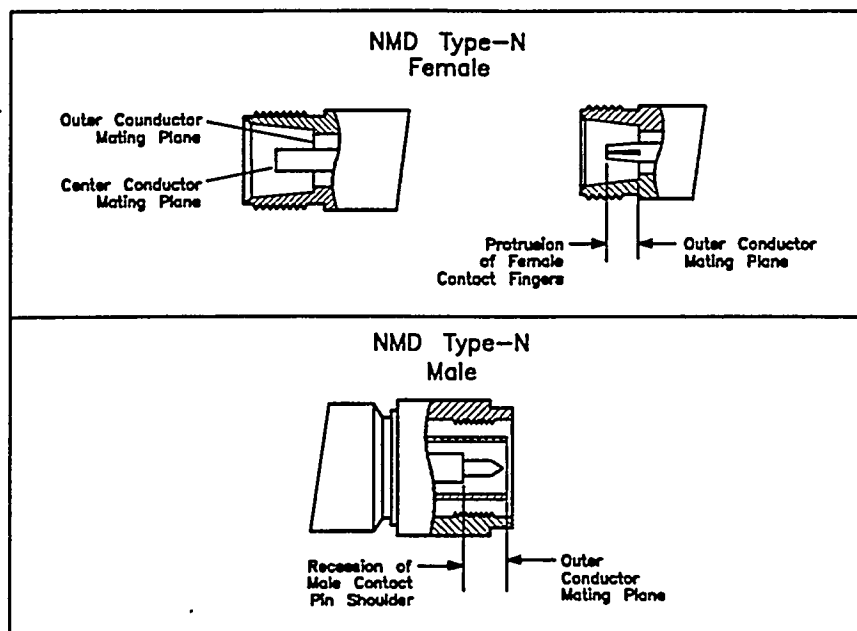
The microwave standards project of the Measurement Standards Program (MSP) is responsible for the calibration of microwave power meters; both CW (continuous wave) average power and pulse power. The project maintains semi-automated calibration systems to accomplish power meter calibrations for the DOE NWC (Department of Energy Nuclear Weapons Complex) and Sandia line organizations.

Each calibration system usually terminates with a test port. The microwave device that serves as a test port is usually a directional coupler, power splitter or attenuator. The requester's power meter is attached to this test port during calibration. The test port of the calibration system is usually composed of a Type-N(f) [female] connector because the power meter to be calibrated has a sensor usually fitted with a Type-N(m) [male] connector.

## Type-N Connectors

Type-N connectors have offset mating planes (see Fig.1). That is, the outer conductor mating plane is offset from its center conductor mating plane. This holds true for both female and male connectors. With the female connector, the center conductor contact fingers protrude ahead of its outer conductor mating plane. With the male connector, the contact pin shoulder recedes behind its outer conductor mating plane.

When the connectors are brought together, the outer conductor mating plane of the male should come into contact with the outer conductor mating plane of the female. The tip of the female connector contact fingers approach, but must not interfere with the male contact pin shoulder. Electrical contact is made by the female contact fingers on the male contact pin. In the event there is any interference between the tip of the female contact fingers and the shoulder of the male contact pin, mechanical damage to one or both connectors may result.



**Figure 1. Type-N Microwave Connector**  
(Reprinted with permission from  
Hewlett Packard Company).

## Type-N Connector Mechanical Specifications

The following Type-N connector mechanical specifications (see Table 1) ensure that any damaging connector interference does not occur.

Under the MIL-C-39012 Class I specification (which applies to many Type-N connectors), the following may be seen:

1. The minimum allowable recession of the shoulder of the male contact pin from its outer conductor mating plane is 0.208" for a male connector.
2. The maximum allowable protrusion of the female contact fingers beyond its outer conductor mating plane is 0.207" for a female connector.

If two Type-N connectors having these minimum and maximum specifications are mated, a Contact Separation (*distance between the male contact pin shoulder and the tip of the female contact fingers*) of 0.001" will be achieved. This clearance of 0.001" will meet the MIL-C-39012 Class I Contact Separation range specification of 0.001"-0.007" and will prevent damage to either connector and also result in near optimum electrical performance of the connector pair.

The EDM process is capable of salvaging a Type-N(f) connector that falls outside the MIL-C-39012 Class I specification because of insufficient protrusion of its center contact fingers.

Specification	Recession (Male)	Protrusion (Female)
MIL-C-71B	0.214 – 0.232 in CONTACT SEPARATION	0.187 – 0.207 in 0.007 – 0.045 in
MIL-C-39012 Class II	0.208 in, minimum CONTACT SEPARATION	0.207 in, maximum 0.001 in, minimum
MIL-C-39012 Class I	0.208 – 0.211 in CONTACT SEPARATION	0.204 – 0.207 in 0.001 – 0.007 in
HP Precision	0.207 – 0.210 in CONTACT SEPARATION	0.204 – 0.207 in 0.000 – 0.006 in

**Table 1.** Mechanical Specifications, Type-N Connectors  
(Reprinted with permission from  
Hewlett Packard Company).

## Reflection Coefficient Magnitude

Reflection coefficient is a complex quantity consisting of a magnitude and phase angle. Reference [1] describes the quantity in detail for the interested reader. Reflection coefficient may be expressed as  $\Gamma_{\text{load}}$  for a microwave power meter, and  $\Gamma_{\text{gen}}$  for a microwave signal generator (During calibration of power meters, the generator is actually an *equivalent generator* consisting in part of a directional coupler, power splitter, attenuator, etc. that serves as the test port).

When calibrating microwave power meters, we are usually interested only in the magnitude of  $\Gamma_{\text{gen}}$  and  $\Gamma_{\text{load}}$  which is equal to:

$$\text{Magnitude of } \Gamma_{\text{gen}} = |\Gamma_{\text{gen}}| = \rho_{\text{gen}} \quad (1)$$

$$\text{Magnitude of } \Gamma_{\text{load}} = |\Gamma_{\text{load}}| = \rho_{\text{load}} \quad (2)$$

The incident power supplied to a microwave power meter during calibration is either reflected by, or dissipated in its sensor [2]:

$$P_{\text{inc}} = P_{\text{ref}} + P_{\text{dis}} \quad (3)$$

The square of the *reflection coefficient magnitude*, ( $\rho_{\text{load}}$ ) of a microwave power meter sensor is a factor in the relationship which determines what portion of the incident power  $P_{\text{inc}}$  will be reflected from the sensor  $P_{\text{ref}}$  [2]:

$$P_{\text{ref}} = \rho_{\text{load}}^2 P_{\text{inc}} \quad (4)$$

Reflection coefficient magnitude also contributes to what is *usually* the largest source of measurement error known as Mismatch Uncertainty, which is discussed in the next section.

Reflection coefficient magnitude  $\rho_{\text{gen}}$  of a microwave source, such as the calibration test ports that are utilized in power meter calibration systems, also contributes to mismatch uncertainty.

## Mismatch Uncertainty

Because of a likely mismatch in the values of  $\rho_{\text{gen}}$  and  $\rho_{\text{load}}$ , the transfer of power from a generator (test port) to a microwave power sensor (load) cannot be known exactly. This is because the generator power is being partially reflected by the power sensor initially, only to be followed by many subsequent re-reflections occurring between the generator and the power sensor [3].

Fortunately, if the reflection coefficient magnitude of the test port,  $\rho_{\text{gen}}$ , and the reflection coefficient magnitude of the power sensor,  $\rho_{\text{load}}$ , are known, the maximum and minimum values of mismatch uncertainty ( $M_u$ , expressed in dB), may be calculated [4]:

$$M_{u \text{ max}} = 10 \log(1 + \rho_{\text{gen}} \rho_{\text{load}})^2 \quad (5)$$

$$M_{u \text{ min}} = 10 \log(1 - \rho_{\text{gen}} \rho_{\text{load}})^2 \quad (6)$$

$$\text{or } M_u = 10 \log(1 \pm \rho_{\text{gen}} \rho_{\text{load}})^2 \quad (7)$$

Mismatch uncertainty in percent relative deviation follows:

$$\%M_u = 100[(1 \pm \rho_{\text{gen}} \rho_{\text{load}})^2 - 1] \quad (8)$$

A demonstration of the validity of Equation 8 as derived from Equations 5 and 6 may be found in Reference [5].

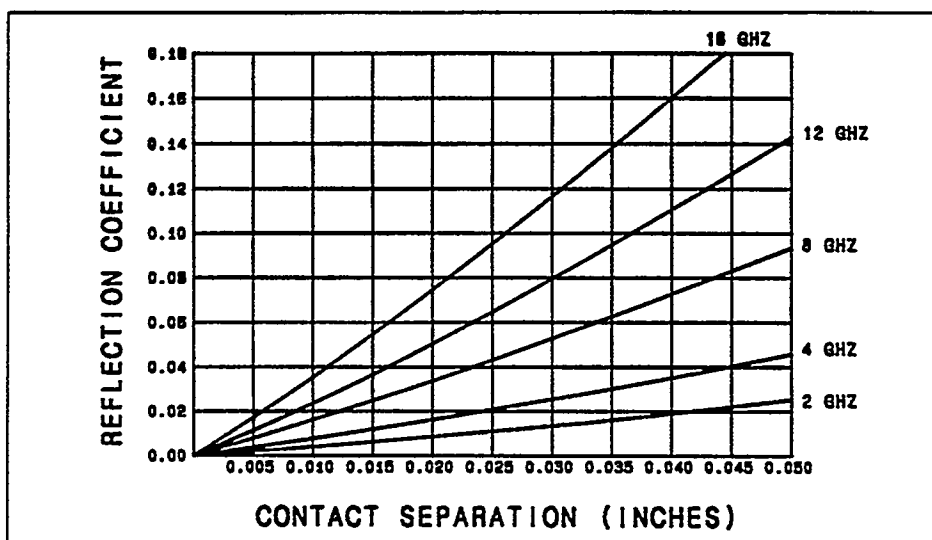
## Electrical Effects of Contact Separation

Ideally, one would prefer to have zero contact separation between the shoulder of the male contact pin and the tip of the female contact fingers when Type-N connector pairs are mated. Practically speaking, this condition does not occur very often.

As shown in Table 1, the MIL-C-39012 Class I specification has a contact separation range of 0.001"– 0.007". So, the minimum contact separation, or gap discontinuity of the center conductor pair was seen to be 0.001". If any contact separation at all exists, that separation will affect the values of  $\rho_{\text{gen}}$  and  $\rho_{\text{load}}$ , thereby influencing the calculated value of mismatch uncertainty.

Figure 2 shows the approximate effects of contact separation on the reflection coefficient of Type-N connections (reflection coefficient as a function of contact separation) for frequencies from 2 GHz to 18 GHz.

It may be seen that as contact separation increases, so does the reflection coefficient of a mated connector pair. Notice that the effect is more pronounced as signal frequency increases. If contact separation is limited to levels between 0.001" and 0.007", as called for by the MIL-C-39012 Class I specification, the increase in reflection coefficient should be less than 0.03 up to 18 GHz.



**Figure 2. Approximate Effects of Contact Separation on Reflection Coefficient, Type-N Connectors**  
(Reprinted with permission from Hewlett Packard Company).

The electrical performance of Type-N adapter pairs having unavoidable discontinuities is discussed in Reference [6].

### **Problem: Out of Specification Type-N(f) Connectors**

In the process of selecting microwave components for power meter calibration, a problem is sometimes encountered: Microwave components having connectors not meeting the MIL-C-39012 Class I specification. These components are usually older, but otherwise perfectly acceptable, microwave devices. For reasons discussed earlier in this report, test ports must meet the "specification".

Microwave components selected as potential candidates for service as test ports, but having Type-N(f) connectors, that do not meet the *less than minimum* protrusion specification, must be disqualified. In an effort to salvage the components falling outside the specification, machining the connector was investigated.

It was understood that material needed to be removed from the outer conductor mating plane to bring the connectors back into specification (see Figure 1). Removing material from the mating plane would increase the protrusion of the contact fingers and solve the problem.

We discussed the problem with several machinists who collectively expressed the opinion that the device was not able to be machined without disassembly—this was not feasible. One of the machinists suggested that we might want to discuss the problem with Sandia's Miniature Machining Group.

### **Solution: Electrical Discharge Machining**

Our visit to the "Miniature Shop" was very productive. A machinist there suggested an unconventional machining technique called: Electrical Discharge Machining (EDM). We found that EDM could bring Type-N(f) connectors having less than minimum protrusion, back into specification quickly and economically.

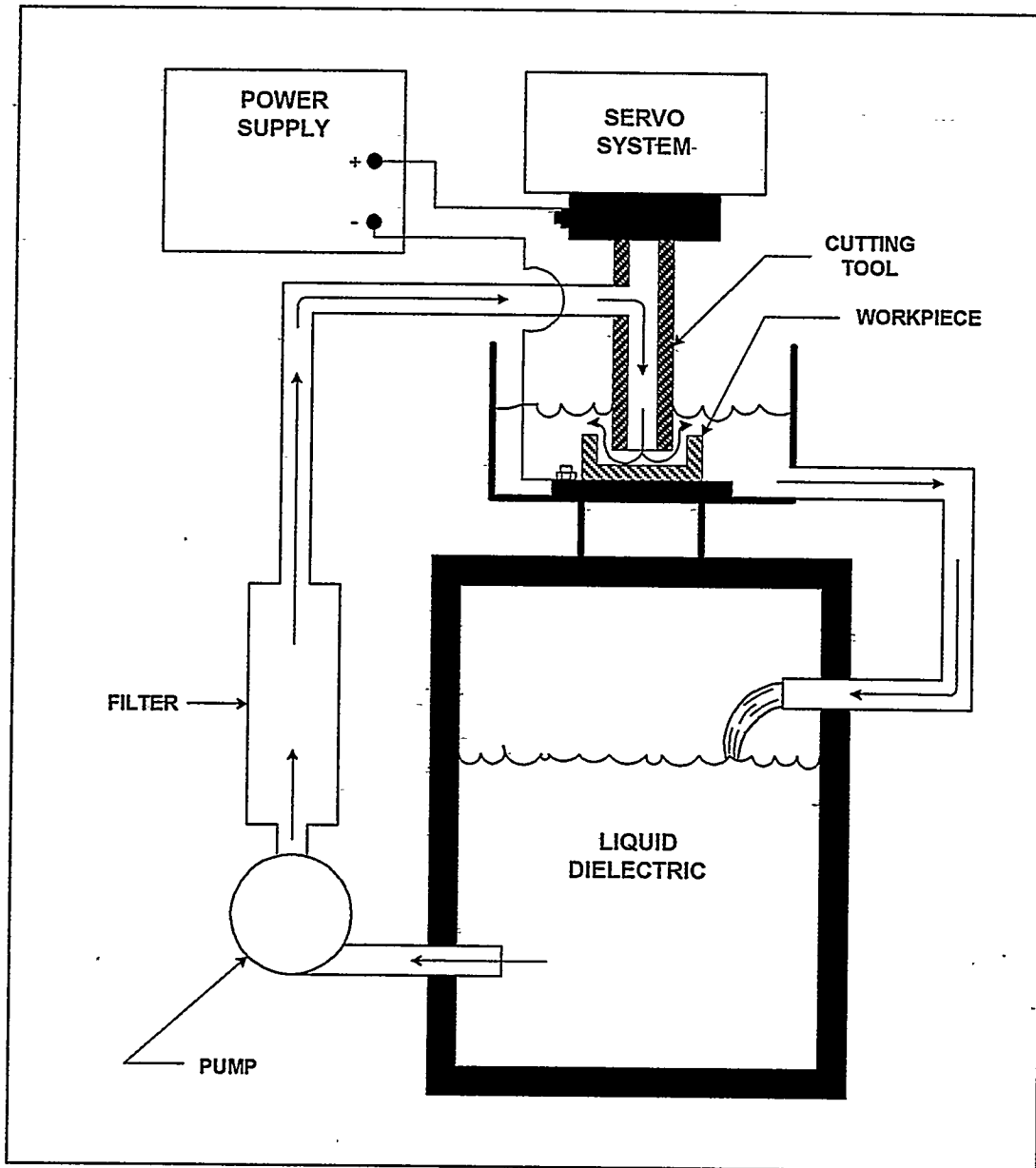
The technique was able to precisely remove material from the outer conductor mating plane. The machining operation could also be accomplished without disassembling our microwave component! Accurate mechanical tolerances could be precisely achieved. This was very important, because if too much material was removed from the mating plane, excess protrusion of the contact fingers would result; thereby, rendering the device useless as a calibration test port! A potential interference condition would exist if a microwave power meter sensor was mated to this test port—possibly damaging both female test port connector, as well as the male connector of the sensor. The EDM technique turned out to be an ideal solution to our problem.

Sandia recently developed innovative methods of EDM to shape parts using a *wire EDM technique*—a variation of the technique described in this report. This method was used to make accurate cuts in a Sandia developed *superconducting gravity gradiometer*, which was composed of niobium—a metal difficult to machine conventionally [7].

## Basic Components of Electrical Discharge Machining

The basic components of EDM are shown in Figure 3. The power supply provides a source of direct current pulses. The positive side of the supply is connected to the cutting tool (anode), with the negative side connected to the workpiece (cathode). This power supply provides a potential difference between the cutting tool and the workpiece across a liquid dielectric.

The machining process takes place entirely in a tank. The tank is part of a dielectric re-circulating system composed of a storage tank, pump, filter, and associated piping.



**Figure 3.** Components of Electrical Discharge Machining  
(Adapted with permission from Vega Enterprises Inc.).

## Electrical Discharge Machining Process

According to the most plausible theory [8], Electrical Discharge Machining utilizes a pulsating direct current to produce a localized heating effect that melts and vaporizes metal. This is the fundamental process behind EDM.

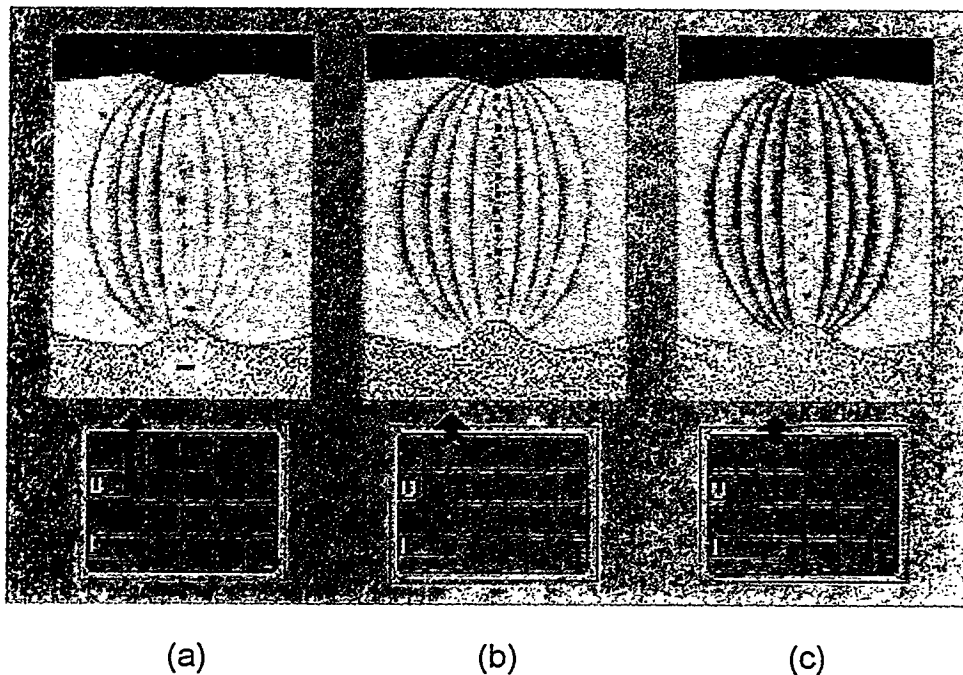
### Visualization of Electrical Discharge Machining Process

The EDM process is essentially invisible. A basic requirement for the process to take place is that both cutting tool and workpiece be electrically conductive. The cutting tool and workpiece are electrodes. In our visualization; the tool forms the positive electrode (anode) and the workpiece becomes the negative electrode (cathode).

See Figure 4. At left, in Figure 4(a), the voltage across the electrodes is maximum and results in an electric field developed across the dielectric gap.

This electric field aligns conductive particles suspended in the liquid to form a bridge as seen in Figure 4(b). Electrons emitted from the cathode proceed along this conductive bridge to the anode; and in doing so, ionize molecules in the liquid dielectric.

This ionization forms a highly conductive channel consisting of many negative and positive particles as seen in Figure 4(c). Also seen, is an initial spark formation (electrical discharge), and a rise in current flow, with an attendant drop in voltage across the gap.

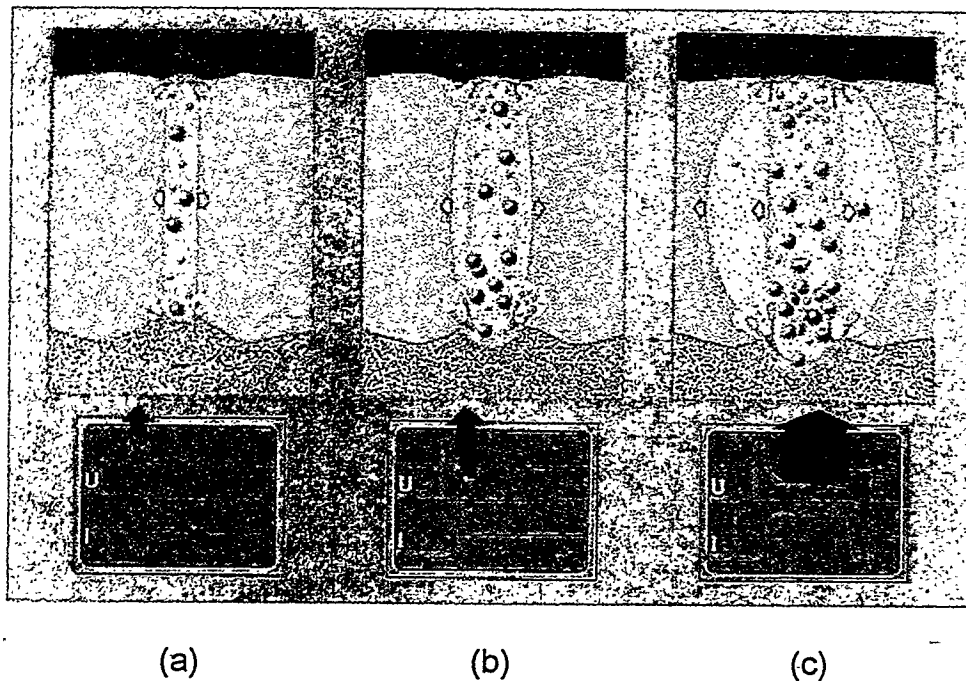


**Figure 4.** Creation of Conductive Channel by Ionizing Collisions  
(Reprinted with permission from AGIE USA Ltd.).

Next, as shown in Figure 5(a), a "column of electrical discharge" called a discharge column [8], extends completely between the anode and cathode as current flow, heat, and pressure all increase. Heat conducted from this discharge column begins to melt the electrodes. This heat has been estimated to generate temperatures that range between 1,100°C to 2,600°C [8].

In Figure 5(b), a further increase in current flow causes the discharge column to expand creating a vapor bubble.

The discharge column and vapor bubble continue to expand as shown in Figure 5(c) depending on the current level and pulse duration. This expansion is limited by the confining pressure of the liquid dielectric.



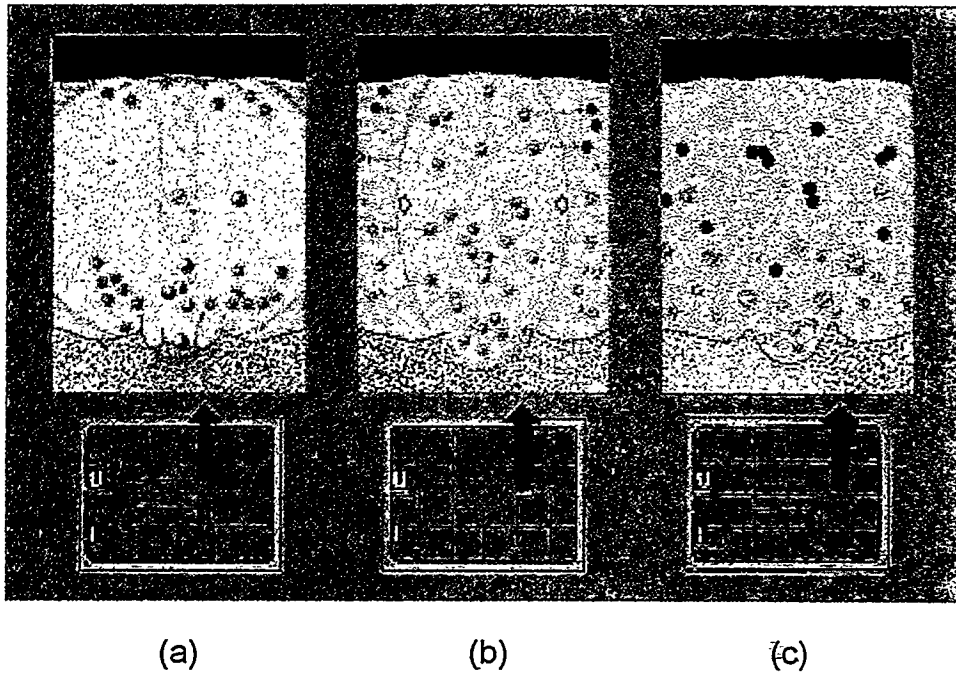
**Figure 5.** Expansion of Discharge Column and Vapor Bubble  
(Reprinted with permission from AGIE USA Ltd.).

In Figure 6(a), when the current drops near zero, there is a corresponding drop in the number of ionized particles, accompanied by a rapid drop in pressure of the discharge column, which causes it to collapse. Molten metal is then explosively ejected as small spherical balls, resulting in the formation of craters in the electrodes.

In Figure 6(b), the vapor bubble collapses allowing an intrush of dielectric fluid to quench any molten metal.

In Figure 6(c), the metal particles and other by-products of "machining" are carried away by the dielectric fluid.

The process is repeated with a rise in voltage of the next direct current pulse.



**Figure 6:** Collapse of Discharge Column and Vapor Bubble  
(Reprinted with permission from AGIE USA-Ltd.).

### Electrical Discharge Machining Technique.

The machinist may adjust the following power supply parameters independently of one another to control the rate of metal removal, tool wear, desired surface finish, etc.:

- ♦ *Pulse voltage*
- ♦ *Pulse discharge current*
- ♦ *Pulse duration*
- ♦ *Pulse interval* (rest between pulses)

### Pulse voltage:

A minimum voltage level must exist across the *tool/workpiece* gap for an electrical discharge to be established, and maintained through the liquid dielectric. The rectangular pulse level used normally ranges between 60 and 100 volts.

A critical requirement of EDM is the maintenance of a small physical gap between the tool and the workpiece. The required gap ranges from approximately 6 thousandths to as little as a few *ten thousandths* of an inch! [9] EDM depends on an electrical discharge between the tool and the workpiece for machining to take place. If the gap is *too great*—no machining will occur. If there is *no gap*, a short circuit will exist between the tool and the workpiece, and again—no machining will occur. The servo system *automatically* maintains the precise gap required for machining to be sustained.

### Pulse discharge current:

The volume of metal removal is directly proportional to the pulse energy. Therefore, as discharge *current* increases (pulse duration held constant), the volume of metal removed—per pulse—will increase. This parameter has a direct effect on the machined surface finish:

- ♦ High current pulses remove more metal per pulse, and produce a rougher finish
- ♦ Low current pulses remove less metal per pulse, and produce a smoother finish

Machining current levels normally range from less than 1 Ampere to about 15 Amperes. Some EDM machines have pulse discharge current capabilities of up to 100 Amperes.

### Pulse duration:

Generally, increasing the pulse duration increases the rate of metal removal; but only up to a point. As the pulse duration is increased beyond a certain period—the rate of metal removal begins to diminish. Fortunately, as pulse duration increases, tool wear tends to decrease. Therefore, a pulse duration may be selected which results in an increased rate of metal removal (before rate diminishes) and a low tool wear [10].

### Pulse interval:

Most often, decreasing the pulse interval (increasing duty factor), increases the rate of metal removal with a reduction in tool wear. But, if the pulse interval is reduced beyond a certain point—a decreased metal removal rate with increased tool wear will result. This point is known as the *marginal duty factor* [10].

Good machining technique must also insure that an adequate flow of liquid dielectric through the gap between the tool and workpiece exists. The dielectric removes heat and the by-products of machining, and can affect the overall machining result. See the flow path for the liquid dielectric in Figure 3.

## Advantages of Electrical Discharge Machining

EDM has two real advantages over conventional machining methods [11]:

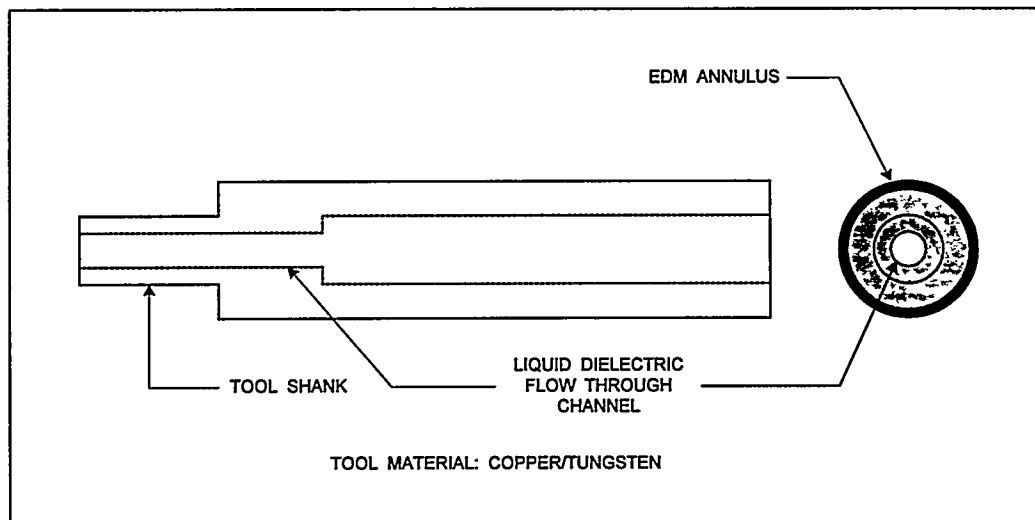
1. Its ability to machine metals of any hardness.
2. Its ability to machine precise holes or intricate shapes of almost any kind.

It has another important advantage over conventional machining: the ability to machine parts of assemblies—*without disassembly*. This was important when machining our microwave connectors. It saved time, and thus proved to be very cost effective.

### Electrical Discharge Machining of Type-N(f) Microwave Connectors

The machining of Type-N(f) microwave connectors, using EDM, is relatively straightforward. The first step is the fabrication of a cutting tool (electrode). The machinist uses a conventional metal turning lathe to fabricate the tool shown in Figure 7. The tool is fabricated out of copper/tungsten alloy in about 30 minutes. Notice the *liquid dielectric flow through channel*. This is machined into the tool to provide an adequate flow of liquid dielectric around the tool/workpiece gap during machining. The tool is held in the EDM machine by the *tool shank*.

Recall that to correct Type-N(f) microwave connectors that do not meet the less than minimum protrusion specification—material must be removed from its outer connector mating plane. The outer diameter of the tool is machined to be similar in dimension to the outside diameter of the outer conductor mating plane. During machining, the tool is moved close to the outer conductor mating plane so machining will take place. The *EDM annulus* defines the area machined, or eroded, on both tool and microwave connector.



**Figure 7.** EDM Tool Used to Machine Type-N(f) Microwave Connectors.

After the tool is fabricated, the next step is to install it in the EDM machine. An out-of-specification microwave component—a directional coupler, for example—is installed in the EDM machining tank. Liquid dielectric is added to the machining tank. The machinist then establishes the proper machining gap between the tool and the outer conductor mating plane of the directional coupler's Type-N(f) connector. After making some initial pulse parameter adjustments to the EDM power supply—the machining process begins.

The machinist makes a first “cut”, using the initial pulse parameter settings. Next, the amount of material removed is measured with the aid of a microwave connector gage—made specifically for Type-N(f) microwave connectors—to determine if any further pulse parameter adjustments need to be made. The machining process continues in this way with subsequent cuts. When the proper amount of material has been removed from the outer conductor mating plane of the connector to bring it into specification, the machining process is complete.

EDM machining of these Type-N(f) connectors was able to bring them back into specification within a tolerance of  $\pm 0.0005$ ”.

Example:     A directional coupler having a connector with a less than minimum protrusion specification of 0.200” was machined using EDM. After machining, the protrusion was 0.206”. This placed it within 0.001” of the maximum protrusion specification called for by MIL-C-39012 Class I.

This met our requirements exactly.

## **Conclusion**

Out-of-specification Type-N(f) connectors on otherwise perfectly acceptable microwave devices disqualified them from being used as test ports in microwave power meter calibration systems. This problem was solved quite readily by reclaiming these devices using the Electrical Discharge Machining technique provided by the Miniature Machining Group at Sandia National Laboratories. The technique proved to be fast, accurate, and economical. The EDM process is superior in many applications when the machining task is difficult or impossible to accomplish using conventional machining practices.

## References

1. *Fundamentals of RF and Microwave Power Measurements*, Application Note 64-1. Hewlett Packard Co., 1977, pp. 24-25.
2. Ibid., p. 4.
3. Ibid., p. 25.
4. Ibid., pp. 26-27.
5. R. J. Haushalter, *A Technique for Low Level, Wide Range CW Microwave Power Meter Calibrations*, SAND87-1851, 1987, appendix C.
6. T. E. MacKenzie and A. E. Sanderson, *Some Fundamental Design Principles for the Development of Precision Coaxial Standards and Components*, *IEEE Transactions on Microwave Theory and Technique*, Vol. MTT-14, No. 1, p 37, January 1966.
7. Unmasking hidden armaments, *Inside Sandia*, p. 7, January 1996.
8. C. M. Hackler and C. R. Schickner, *Electrical Discharge Machining*. Vega Enterprises, Inc., Decatur, IL, 1969, pp. 5-13.
9. Ibid., p. 4.
10. *Technological aspects of spark erosion*, AGIE, Industrial Electronics Ltd., CH-6616 Losone-Locarno Switzerland, pp. 18-21, October 1983.
11. C. M. Hackler and C. R. Schickner, *Electrical Discharge Machining*. Vega Enterprises, Inc., Decatur, IL, 1969, p. 3.

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