CASE 45

Optimization of an Electrical Encapsulation Process through Parameter Design

Abstract: A process used to generate an encapsulant layer, which provides electrical isolation between elements on the outer surface of a night-vision image-intensifier tube, was optimized using Taguchi's L_{18} orthogonal array and SN ratio. This parameter design effort was launched in response to the need to optimize an encapsulation process using a lower processing time and temperature to cure the encapsulant. The SN ratio of the engineered encapsulation system was increased 7.2 dB compared to baseline conditions, and β, the slope of the ideal function, was reduced from 0.6298 to 0.1985, or 68%. As a result of this process improvement effort, a new encapsulant was qualified using a process temperature reduced by 20% and process cycle time reduced by 40%.

1. Introduction

We used Taguchi's dynamic parameter design approach to optimize an electrical encapsulation process. Here we present a parameter design effort focused on reducing the process cycle time and curing temperature while maintaining the same reliability performance for the image sensor module used in the night-viewing product lines at ITT Night Vision.

Figure 1 shows an F5050 system that has two sensor modules (Figure 2), one located behind each objective lens opposite the eyepiece. At the heart of each module is an image intensifier tube (Figure 3), whose outer surface has exposed electrical elements that must be covered to provide environmental isolation.

In addition, the material covering the tube's surface must isolate the exposed metallic elements electrically. The space allowed for the encapsulant material is very small, to reduce sensor module weight and size, increasing the challenge of introducing a new encapsulant material. A paramount constraint on this engineered system is temperature exposure. The image tube cannot be exposed to temperatures greater than 95°C to maintain the tube's ability to amplify low levels of input light uniformly and consistently over time (stable luminous gain).

2. Background and Objectives

ITT customers require robust products that endure environmental extremes. This robustness is measured using a test involving thermal excursions while simultaneously exposing the viewing device and image sensor module to a wide range of relative humidity. Image sensor module reliability was defined at the customer's quality level as the ability of the device to maintain luminous gain over time. (Luminous gain is the light-amplifying power of the image sensor module.)

The historical approach for improving the reliability of the product and image sensor module was to evaluate design and process changes while ex-

 Taguchi's Quality Engineering Handbook. Genichi Taguchi, Subir Chowdhury and Yuin Wu

Figure 1
F5050 night vision goggle

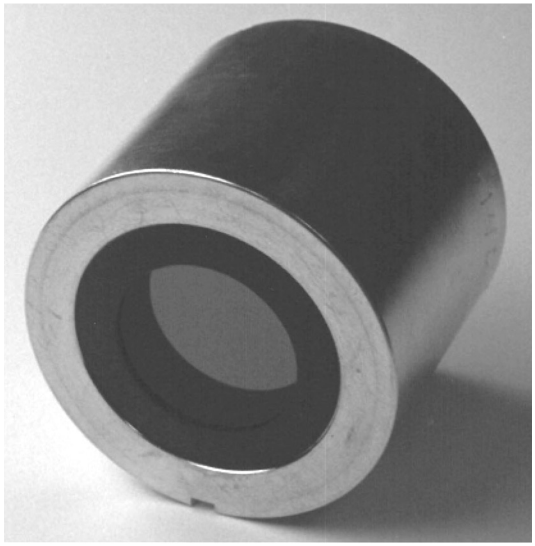

Figure 2
Cross section of sensor module

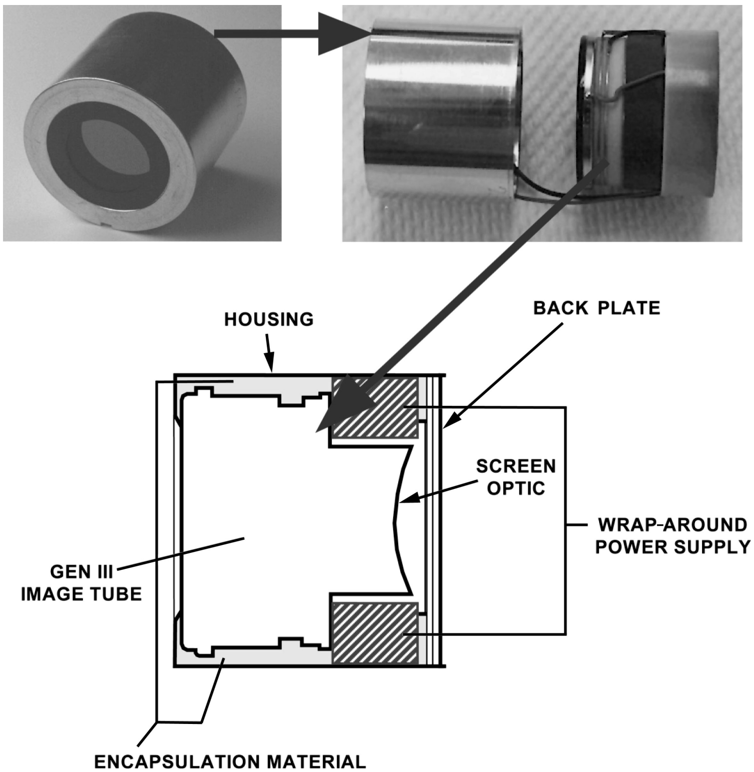

Figure 3
Cross section of image-intensifier tube

posing these devices to a customer's environmental test. These evaluations were typically single factorial in nature, and the quality characteristic measured was number of cycles until the device's luminous gain degraded past a certain value or the total percent of gain degradation. For this experiment, a sample coupon was used to investigate the ideal function of the encapsulant in order to develop the encapsulating/insulating technology independent of the product on which it was used.

At the engineering quality level, the quality characteristic used was interface leakage current measured at several voltage potentials applied between an electrode on a sample coupon, not the image sensor module itself.

Figure 4 shows a representation of the coupon used to gather the data needed to generate the dynamic SN ratio and slope. This metric was used to select the best levels of the controllable factors in the encapsulating/insulating engineered system. The coupon consisted of a ceramic substrate with a set of evenly spaced electrode lines deposited on its surface. The approach was to minimize the slope of the ideal function, thus reducing the effect of the noise factors while reducing leakage current proportional to applied voltage.

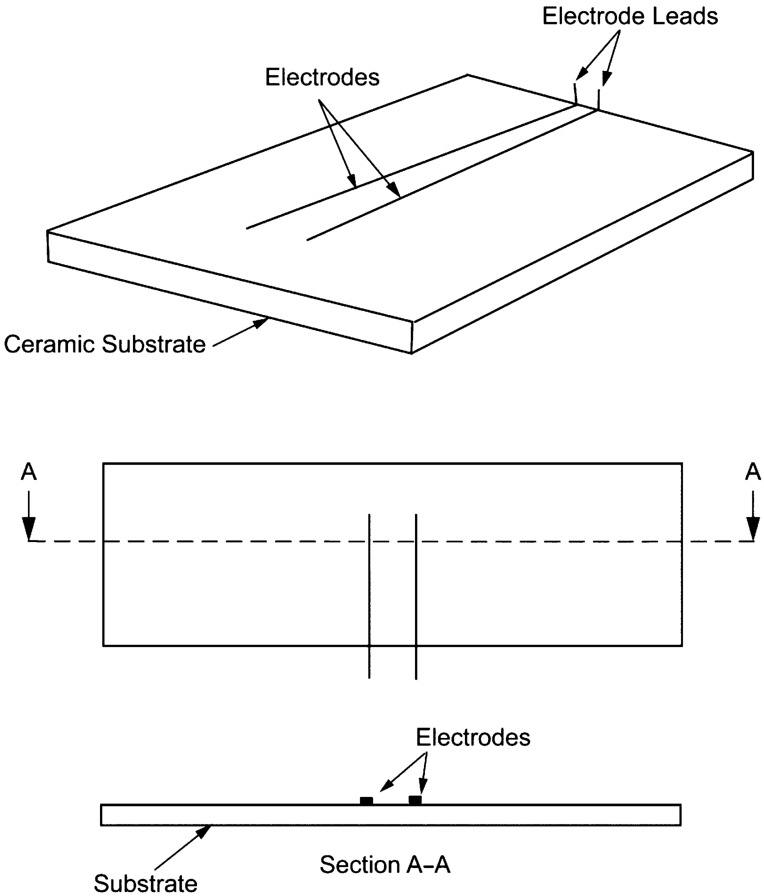

Figure 4
Test coupon to simulate the product

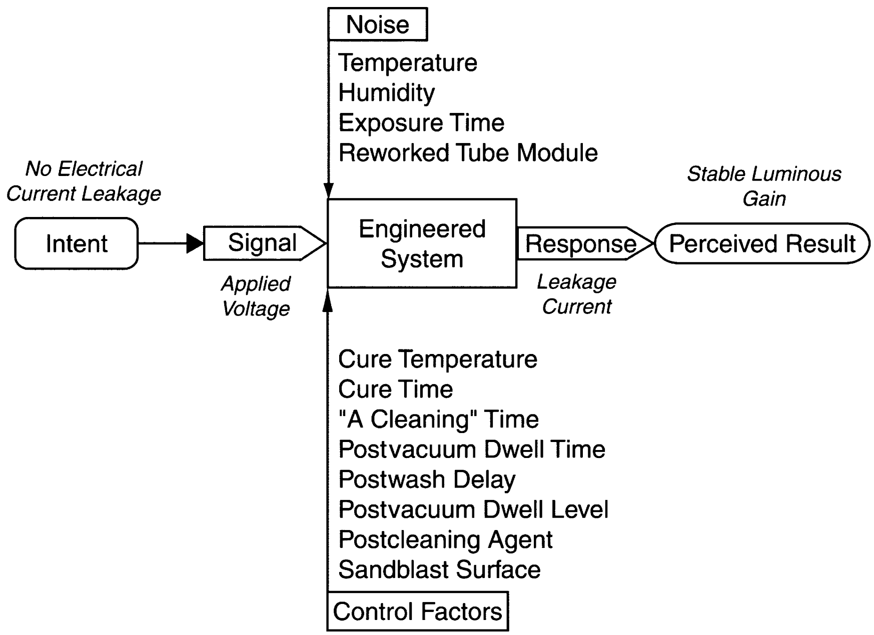

Figure 5
Encapsulation system

3. Parameter Design Experimental Approach

Figure 5 presents the encapsulating/isolating engineered system. The signal factor is applied voltage. The response is the resultant current flow between the metallic elements. Figure 6 presents the ideal function for the system. The compound noise factor was thermal/humidity exposure, performed cyclically over many days, as well as the condition of the coupon simulating a reworking situation. The electrical data were collected before and after this cycling. The data were analyzed using the zero-point proportional dynamic SN ratio using applied voltage as the signal factor. The objective was to minimize the slope, β. For the ideal function of voltage versus current, the slope is inversely proportional to resistance, and for this system, the objective was to maximize resistance in order to increase the electrical isolation properties of the encapsulant system.

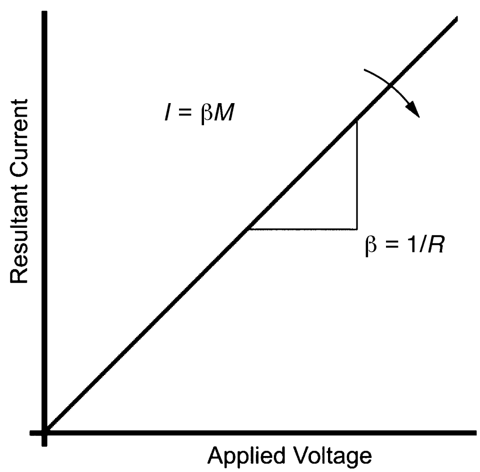

Figure 6
Ideal function

Table 1
Factors and levels

Factor	Level
Signal factors	
M: voltage between electrodes (V)	1: 2000
	2: 4000
	3: 6000
	4: 8000
Controllable factors	
A: cure temperature (°C)	1: 60
	2: 80
B: cure time (h)	1: 2
	2: 4
	3: 6
C: "A cleaning" time (min)	1: 5
	2: Std.
	3: 30
D: postvacuum dwell time (min)	1: 0
	2: 5
	3: 10
E: postwash delay (h)	1: <0.5
	2: 12
	3: 24
F: postvacuum dwell level (torr)	1: 250m
	2: 2
	3: 200
G: postcleaning agent	1: IPA
	2: Std.
	3: Acetone
H: sandblast surface	1: Light
	2: Std.
	3: Heavy
Noise factors	
X: humidity/temperature	1: Before
	2: After
Y: coupon condition	1: New
	2: Reworked

Table 3
Experimental results

Row	SNR (dB)	Slope, β
1	−16.5406	1.9895
2	−15.6297	0.7347
3	−14.5655	0.6423
4	−15.3339	0.928
5	−14.9945	0.6889
6	−18.344	0.7758
7	−15.4606	0.9989
8	−15.1447	0.8003
9	−15.77	0.2967
10	−14.9883	0.4587
11	−15.7399	0.1666
12	−16.3414	0.5862
13	−18.0843	0.4627
14	−15.2836	0.3669
15	−17.7041	0.5584
16	−15.9816	0.1713
17	−16.9162	0.8485
18	−14.4645	0.2468

4. Experimental Layout

Table 1 lists the factors and levels used in the L_{18} experimental layout. Thirty-six coupons were fabricated, half of which were treated to represent one of the noise factors called "reworked." Each was encapsulated according to the orthogonal combinations using the process developed for sensor module

Table 2
Baseline raw data

2 kV				4 kV				6 kV				8 kV	
Rework		New		Rework		New		Rework		New		Rework	
Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
0.041	1.59	0.056	5.05	0.131	3.61	0.118	8.01	0.252	6.02	0.205	10.93	1.25	9.13

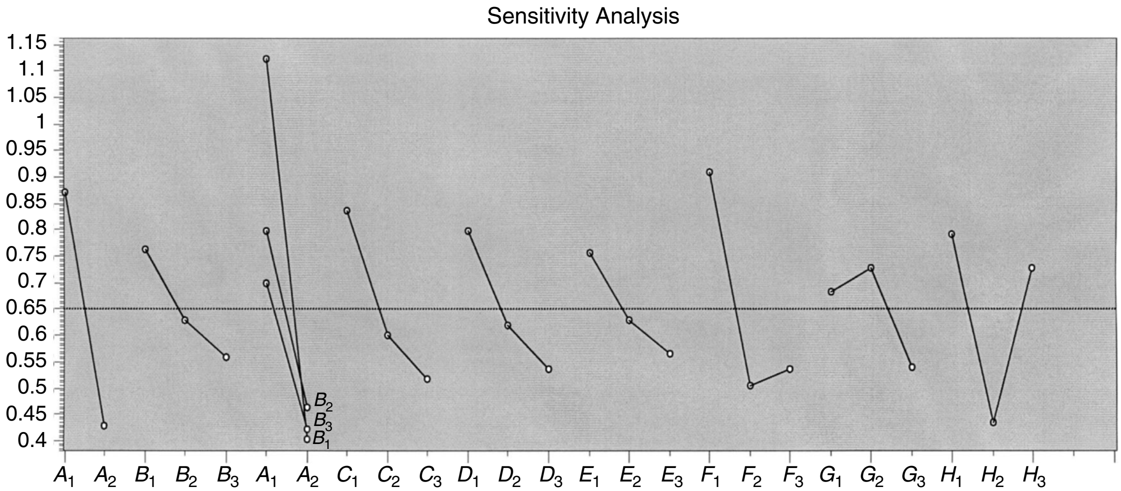

Figure 7
Average response graph for β

fabrication. Once these were encapsulated, all the "before" electrical measurements were obtained, and then the coupons were exposed to repeated cycles of temperature and humidity. Then each was tested again for the electrical characteristics, and the data collection sheets were completed.

5. Experimental Results and Analysis

The electrical current measurements made on the 36 coupons for each voltage potential before and after thermal/humidity exposure are too numerous to present here. The SN ratio and β were calculated for the 18 combinations of control factors and used as the system response for analysis in the orthogonal array.

Process Baseline

Before the parameter design experiment began, the existing encapsulation system was baselined by producing a coupon under standard conditions and making the measurements shown in Table 2. The baseline SN ratio is −14.61 and the baseline β value is 0.6298.

η and β ANOVA Tables and Response Graphs

Table 3 presents the η and β values that resulted from the L_{18} experiment. These values were generated using data from the zero-point proportional dynamic SN ratio equation. Of particular importance in Table 3 is the large range in β values. It was the objective of the study to find control factors that influence β, adjusting their levels to *minimize* β. Figure 7 presents the factor-level average response graphs for 10 log β^2. The best levels focusing on minimizing β are A_2, B_1, C_3, D_3, E_3, F_2, G_3, H_2.

Table 4
Process average and confirmed values

	Process Average Estimate		Confirmed Value	
Condition	**η (dB)**	**β**	**η (dB)**	**β**
Baseline	—	—	−14.61	0.6298
Optimum	−15.12	0.1256	−7.42	0.1985
Gain	—	—	7.19	0.4313

6. Confirmation

Table 4 presents the process average estimates and confirmation results for η and β. Figure 8 compares

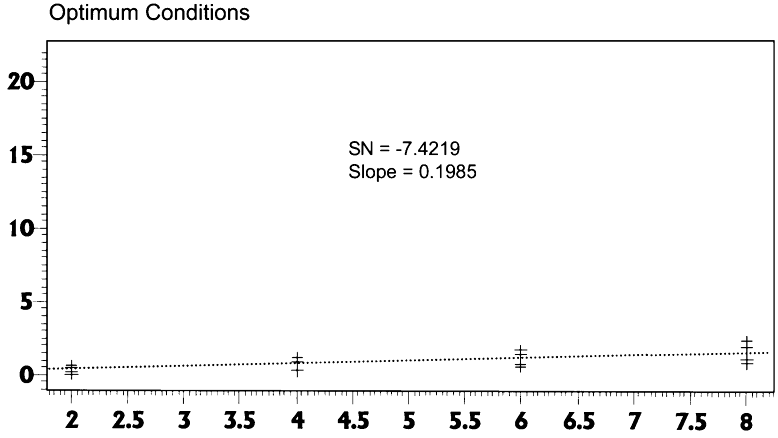

Figure 8
Optimum versus standard process conditions

the reduced slope confirmation to the standard process baseline, showing the improvements in both SNR and slope.

7. Conclusions

As a result of the parameter design effort focused on the electrical encapsulation engineered system, the SN ratio increased 7.2 db while decreasing the slope, β, 68% from 0.6298 to 0.1985. This translated into a 20% reduction in processing temperature and a 40% reduction in cycle time. Of far more importance is the improvement in encapsulation technology because the parameter design effort was performed on coupons and focused on improving the function of the system independent of product application.

This case study is contributed by Joe Barker, William Finn, Lapthe Flora, and Ron Ward.