Using Curve Tracing to Detect Counterfeit Components

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Contact RTI for a longer more in depth version of this presentation

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Which one of these is not like the other?
When to suspect devices

Red Flags for High Risk Parts

- Untraceable old stock
- Old date codes
- Hard to find devices
- High Value devices
- Not Purchased from the OEM or an authorized distributor
- Speed Graded devices
- High Reliability devices
Types of Counterfeits

What types of counterfeit devices are there?

- Complete fakes
  - Random function remarked devices, only the package resembles what was ordered
- Rebranded, Imitation or Copy Components
  - Similar function but from an unknown source
- Rejected Components
  - Real but otherwise previously failed devices
- Recycled Components
  - Real but otherwise previously used devices
  - 80 to 90 % of all counterfeits*
- Remarked Components
  - Same function but inferior specs

Source: SMT Corp. as reported by IEEE Spectrum October 2013 issue
“The Hidden Dangers of Chop-Shop Electronics”
Detection Methods

- **Question:** How can this be done; Verify that an IC you bought is genuine and quality, that it is not remarked, repackaged, reused or fake?

- **Answer:** Test it and compare it to known good devices. There are many tests available. Some analyze the Physical aspects of the device, some analyze the electrical aspects.
Sensitivity to Types of Test Methods

Which types of test methods are counterfeit devices sensitive to

<table>
<thead>
<tr>
<th>Type of counterfeit</th>
<th>Sensitivity to Physical Analysis</th>
<th>Sensitivity to Curve tracing</th>
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</thead>
<tbody>
<tr>
<td>Fake components</td>
<td>Excellent</td>
<td>Excellent</td>
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<tr>
<td>Rebranded/Imitation</td>
<td>Good</td>
<td>Good</td>
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<tr>
<td>Rejected components</td>
<td>Poor</td>
<td>Good</td>
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<td>Recycled components</td>
<td>Fair</td>
<td>Good</td>
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<td>Remarked components</td>
<td>Good</td>
<td>Poor</td>
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What is Curve Tracing?

- Curve Tracing was originally developed to characterize electron tubes and later transistors and other power semiconductors.
- Used to measure DC Electrical Parameters of discrete semiconductors
- Can be used as a tool for screening devices
- Workhorse tool of the Failure Analysis lab
- Universal Non-Destructive Electrical Test Tool
- Characterizes damage to IC structures
- Measures damage to electronic structures
- Stimulate electrical damage for fault localization methods
Where Curve Tracing is used?

- In what way should I be using a curve tracer?
  - Incoming Receiving and Inspection
  - High Reliability Manufacturing
  - Part Recovery Operations
  - Failure Analysis
Who uses Curve Tracing

Who is using curve tracing for counterfeit interdiction?
- High Reliability manufacturers
- Distributors
- Part Recovery providers
- Law Enforcement
- Laboratory and Analysis Service Providers
I-V Curve Tracing

- Curve Traces are made up of measurements of voltage and current
  - In Ohms Law; \( V = I \times Z \) where \( Z \) is the impedance of the device or pin
  - In semiconductor devices, \( Z \) is usually nonlinear
  - \( Z \) changes as the voltage across the load changes

- A Curve Tracer’s task is to trace out that relationship and convert it into a graph of I vs. V

- Each type of pin has a “characteristic” curve trace shape particular to that pin’s structure

- Collectively the Characteristics of all the pins of a given device provide a sufficient signature or fingerprint for checking device authenticity.
IC Curve Tracing
Curve Tracing Methods

- Hypothetical Model of a CMOS IC circuit

![Simplified Inverter Diagram]
IC Curve Tracing

- The most basic Curve Tracing tasks is to acquire a set of signatures for each device and save that information so that it can be compared to other devices.

- This comparison task is the central method for finding bad devices.

- *If the curve trace results of a suspect device do not match those of a known good and genuine part, then that device is either degraded or different from the known device.*
IC Curve Tracing
IC Curve Tracing

- Collectively the Characteristics of all the pins of a given device provide a sufficient signature or fingerprint for checking device authenticity

- If the curve trace results of a suspect device do not match those of a known good and genuine part, then that device is either degraded or different from the known device
Each set of test conditions produces a unique set of curve trace results. Using multiple test conditions is like getting fingerprint prints from the whole hand. Matching that to a suspect device becomes much more reliable.
IC Curve Tracing
Curve Tracing Equipment

- Manual Curve tracers
  - Limited test conditions, primarily “hand test”
  - Low entry cost

- Automated Curve Tracers
  - Very flexible for IC characterization
  - Designed specifically for characterizing IC devices
  - Offers a balance between Precision and Flexibility
  - Allows for screening devices to a tight tolerance, accuracy and repeatability
  - Flexibility for a wider range of devices
  - Wide variety of test conditions
Curve Tracing Equipment

- **Automated Curve Tracers**
  - Configurable multi channel switch matrixes
  - Multiple SMU (Source Measure Units) available
  - Obtain I-V Signature and IDD
  - Provide multiple bias voltage or current to devices
  - Allows for testing in the powered up state
  - Measurements are generally high precision
  - Software is optimized for configuring various test conditions and analyzing the piles of data that can be produced
Curve Trace Methods

- Three generic test methods sufficiently characterize any device of any technology
  - Unpowered Curve Tracing
  - Powered Curve tracing
  - Supply Current Characterization
Unpowered Curve Tracing

The Unpowered Curve Trace method

- First line of defense
- Simplest test method
- Lowest cost hardware
- Compare known good devices to all or selected samples from a batch of parts to screen out the worst of the bunch
Unpowered Curve Tracing

**Standard Testing Methods:**

- Unpowered
- Powered
- Supply Current

Unpowered curve trace of a device with curves from all pins displayed.
Unpowered Curve Tracing

- What to look for in an unpowered curve trace result
  - **Non matching characteristics**: Certainly with any test condition, if the curves from a suspect device don’t match the golden device you have a problem
    - If it’s a complete mismatch, it’s safe to say that either the device is severely damaged or it is not the same device entirely
    - Smaller variations can be clues to ESD damage, silicon differences or other quality issues.
Unpowered Curve Tracing

- **Things Unpowered curve tracing will find**
  - Failures: Devices with gross damage characterized by Open pins, shorted pins or high leakage
  - Incorrectly bonded devices
  - Fake or wrong die inside
  - Different rev die inside
  - Device matches datasheet pin out

- **Things Unpowered Curve tracing will not find**
  - Remarked devices
  - Reused devices that are good electrically
  - Most forms of damaged package devices with no electrical damage
  - Some Functional Failures; Analog or Digital
**Powered Curve Tracing**

- **The Powered Curve tracing method**
  - Greatly increases test coverage and can discover degraded parts that otherwise look normal by way of unpowered curve tracing.
  - Input and output pins take on more unique curve trace shapes permitting additional parameters that need to match known good devices in order to pass.
  - Supply current is measured in addition to pin I-V curves.
  - May be used to determine test conditions for IDDQ testing.
Powered Curve Tracing

Standard Testing Methods:

Unpowered

Powered

Supply Current

Powered Curve Trace showing a single pin I-V curve and two Supply current curves.

Red = Idd Curve 1
Pink = Idd Curve 2
Blue = I-V Standard
Powered Curve Tracing
Powered Curve Tracing

- **Things Powered curve tracing will find**
  - Same failures as Unpowered curve tracing
  - Degraded inputs or outputs
  - High Supply Current
  - Other supply current switching anomalies

- **Things Powered Curve tracing will not find**
  - Remarked devices
  - Reused devices that are good electrically
  - Functional only Failures; Analog or Digital
Supply Current Characterization

- Broadest test coverage
  - Many problems show up in the supply current

- Simplest Results
  - Just a few simple numbers to collect

- IDDQ can be measured in any state of the device which you can configure repeatably
  - A testable state does not necessarily need to be to an actual functionally valid state.

- Measure IDD from different power domains for greater test coverage
Supply Current Characterization

- Supply current can be measured using other methods like bench supplies and a breadboard.
- Current limits should be set to protect test hardware from burning due to over current short circuit.
- Use the Powered Curve trace to get a broader view of the supply current range and which pins influence it most.
- Choose test conditions based on powered curve trace analysis but screen devices quickly using IDDQ checks.
Things IDD testing will find

- Very High IDD indicates a shorted device
- High IDD in any state indicates damage to the core or pins
- High IDD may accompany other forms of electrical damage
- High IDD only in certain states indicates damaged subcircuits
- Marginally High or low IDD may indicate a degraded device
- Low IDD indicates a circuit that will not activate
- Low IDD may indicate missing or fused open bond wires
- Zero IDD indicates fused open power traces or bond wires
Supply Current Characterization

- **Things IDD testing will not find**
  - Damage to inputs, outputs and I/O pins that do not result in a short to a supply
  - Low level leakage caused by ESD
  - Functional only failures
  - Analog Non Compliance
  - Dynamic or speed related non compliance
  - Package quality problems
Evaluating Results

- Comparing to a known good device
  - Most reliable method when known good devices are available
  - Test more than 1 known good device to learn acceptable variability

- Comparing to the average device
  - Collect curve trace data from a lot of devices and look at each pin as a group
Evaluating Results

- DataTrace post processing software has features designed exclusively for evaluating counterfeit devices and evaluating lots of devices
  - Batch Comparison presents results in bar charts and tables
  - A group of devices that all match well and also match old lots you have previously saved will have high confidence
  - A group of devices with poor match or high failure rate especially as compared to the past lots will have poor confidence
## Evaluating Results

### Results Grid

<table>
<thead>
<tr>
<th>File</th>
<th>File Name</th>
<th>Pin 2</th>
<th>Pin 3</th>
<th>Pin 4</th>
<th>Pin 5</th>
<th>Pin 6</th>
<th>Pin 7</th>
<th>Pin 8</th>
<th>Pin 9</th>
<th>Pin 10</th>
<th>Pin 11</th>
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<th>Pin 13</th>
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**Legend:**
- **Control**
- **Short Fail**
- **Sh+CT Fail**
- **CT Fail**
- **Open Fail**
- **CP+CT Fail**

**Highlight Mode:**
- **Fail**
- **Highlight Failures**
- **Highlight Open/Shorts**

**Short Pin Shorted**
- **Open Pin Open**
- **Fail Curve Test Failed**
- **Curve** - Normal Curve, Passed or Control
- **NA** - No result
Evaluating Results

**Complete fakes**

- These are devices with packaging and markings that may resemble the authentic device but the die inside may be anything but what you thought.. In these the electrical continuity does not come close to matching the genuine device.

  - Unpowered curve tracing has a high sensitivity to this kind of counterfeit. Mismatched curves, opens and shorts should be evident on most pins.

  - Curves can be evaluated against the datasheet when no known good device is available

  - Powered curve tracing and supply current measurements are usually not necessary due to the clear indication from unpowered

  - Physical test methods also do very well at spotting these fakes. These devices are generally easy to spot through marking analysis, decap or x-ray inspection
Evaluating Results

Rebranded, Imitation or Copy devices

- These are devices where the counterfeiter actually made an effort to supply a functional device. Basic functional testing may pass and they might even work in your product.

- Even minor changes in an IC design can change the fingerprint of the curve traces. Curve Tracing turns out to be quite sensitive to this type of fake. While a row of pins may have the same name, if the device inside does not match exactly, the curves will be different, sometimes very different.

- Unpowered curve tracing has a moderate to high sensitivity because if the pin input structure is different like say from a different process, the curve will be somewhat different.

- Since the device was intended to be functionally equivalent, the powered curve tracing, might even be more compliant. However clues in the supply current, IDD switching characteristics and clamp diode forward resistance can show up.

- Physical test methods have a good chance at finding these since the die or other construction details may be different. Since the package as well as the die inside may be fake, most of the methods should have some sensitivity.
Rejected devices

- These are devices that have failed at the factory and were somehow reclaimed by counterfeiters. As good as these devices appear physically, just about every one of them is an electrical failure

  - Curve tracing will find most of these failures. Any failure mode related to a pin is detectable, only deep core functional failures will be undetectable by curve tracing

  - Unpowered curve tracing will have good to very good sensitivity and adding powered curve tracing with its supply current measurements will increase the detection rate to high sensitivity

  - Physical test methods will miss these failed but otherwise authentic devices. For these devices the die inside is real and so is the package and may be undetectable by Marking Analysis, X-Ray, or even internal visual inspection after decap. Tracing the date or lot codes may lead to evidence of scrapping by the OEM
Evaluating Results

Reclaimed devices

- These are or were authentic devices at one time but they are used now. They were once soldered to a PC board assembly and may have even seen a service life. At some point the assembly was scrapped and some devices were recovered.

- Unpowered curve tracing has fair sensitivity to these because many may not have electrical failures.

- Powered curve tracing has the same limitation

- If the device is failed; both curve tracing methods have a very good chance of detecting it

- Physical test methods may detect that the leads are reconditioned or mechanical damage to the package but there may be no other package anomalies and the markings may be authentic.
Evaluating Results

**Remarked devices**

- These are otherwise genuine devices remarked in such a way as to make them more valuable for resale. The device inside may or may not be identical to the actual device.

- This type of counterfeit is the one type that curve tracing is not very good at finding. The devices inside are otherwise good devices matching the known good specimen with respect to its DC characteristics and pin types. The differences lie in the functional properties or maximum AC operation speed. These are areas of electrical test that curve tracing does not do.

- Physical analysis methods have a very high sensitivity to this type of counterfeit. Marking analysis can confirm the validity of things like date codes for the particular part number or consistency of part number suffixes. Such analysis will often reveal discrepancies that will lead to detection of fake part codes or specifics.
Conclusion

Curve tracing can be used to detect a wide range of counterfeit or misrepresented IC devices.

Unpowered curve tracing is used to confirm the pinout and check for gross defects.

Powered Curve tracing goes beyond a reasonable match to confirm many of the DC specifications including supply current. This increases counterfeit detection greatly.

Curve tracing is especially good at finding ESD damaged or high Supply Current (IDDq) caused by mishandling that may degrade or reduce the lifetime in the application circuit.

When used with device markings analysis and physical analysis methods, curve tracing can close the net the rest of the way on nearly all misrepresented devices.
Conclusion

Users can create libraries of known good devices (KGD) for comparison to suspect parts.

Users can save results from each purchased lot and chart the failures in production. This method helps pinpoint signatures of good and bad devices.

Old lots can be used as known good devices for future lot testing.

Curve tracing requires minimal information about the function of the device. A list of pin names and pin type is usually all one needs for a thorough analysis.

Curve tracing is universal to any semiconductor technology and any device package.