

DECLARATION OF JUNE ANN MUNFORD

1. My name is June Ann Munford. I am over the age of 18, have personal knowledge of the facts set forth herein, and am competent to testify to the same.
2. I earned a Master of Library and Information Science (MLIS) from the University of Wisconsin-Milwaukee in 2009. I have over ten years of experience in the library/information science field. Beginning in 2004, I have served in various positions in the public library sector including Assistant Librarian, Youth Services Librarian and Library Director. I have attached my Curriculum Vitae as Appendix CV.
3. During my career in the library profession, I have been responsible for materials acquisition for multiple libraries. In that position, I have cataloged, purchased and processed incoming library works. That includes purchasing materials directly from vendors, recording publishing data from the material in question, creating detailed material records for library catalogs and physically preparing that material for circulation. In addition to my experience in acquisitions, I was also responsible for analyzing large collections of library materials, tailoring library records for optimal catalog

search performance and creating lending agreements between libraries during my time as a Library Director.

4. I am fully familiar with the catalog record creation process in the library sector. In preparing a material for public availability, a library catalog record describing that material would be created. These records are typically written in Machine Readable Catalog (herein referred to as “MARC”) code and contain information such as a physical description of the material, metadata from the material’s publisher, and date of library acquisition. In particular, the 008 field of the MARC record is reserved for denoting the date of creation of the library record itself. As this typically occurs during the process of preparing materials for public access, it is my experience that an item’s MARC record indicates the date of an item’s public availability.
5. Typically, in creating a MARC record, a librarian would gather various bits of metadata such as book title, publisher and subject headings among others and assign each value to a relevant numerical field. For example, a book’s physical description is tracked in field 300 while title/attribution is tracked in field 245. The 008 field of the MARC record is reserved for denoting the creation of the library record itself. As this is the only date reflecting the inclusion of said materials within the library’s collection, it is my experience

that an item's 008 field accurately indicates the date of an item's public availability.

6. I am familiar with the Internet Archive, a digital library formally certified by the State of California as a public library. Among other services that the Internet Archive makes available to the general public is the Wayback Machine, an online archive. The Internet Archive's Wayback Machine service archives webpages as of a certain capture date to track changes in the web over time. The Internet Archive has been in operation as a nonprofit library since 1996 and has hosted the Wayback Machine service since its inception in 2001. During my time as a librarian, I frequently used the Internet Archive's Wayback Machine for research and instruction purposes. This includes teaching instructional classes on using the Wayback Machine to library patrons and using the Wayback Machine to research reference inquiries that require hard-to-find online resources. I consider the Internet Archive's recordskeeping to be as rigorous and detailed as other formal library recordskeeping practices such as MARC records, OCLC records and Dublin Core.

7. I have reviewed Exhibit SOLUS-1025, a paper entitled “Measuring Copper Surface Roughness for High Speed Applications” by John A. Marshall as published in *Proceedings of the 2015 IPC APEX Expo*.
8. Attached hereto as Appendix FRANK-WHITE01 is a declaration by Nathaniel E. Frank-White of The Internet Archive. This declaration describes the Internet Archive’s record for a PDF copy of “Measuring Copper Surface Roughness for High Speed Applications” as hosted on the Circuit Insight website. This record is located at https://web.archive.org/web/20161019124306/https://www.circuitinsight.com/pdf/measuring_copper_surface.
9. Frank-White’s declaration contains a true and correct copy of “Measuring Copper Surface Roughness for High Speed Applications” by John A. Marshall. The URL found on page 4 of this appendix indicates this copy was archived and subsequently made available to the public by the Internet Archive as of October 19, 2016. When comparing Appendix FRANK-WHITE01 to Exhibit SOLUS-1025, it is my determination that Exhibit SOLUS-1025 is a true and correct copy of “Measuring Copper Surface Roughness for High Speed Applications” by John A. Marshall.

10. Attached hereto as Appendix SMITH01 is an email chain between Logan Smith of IPC International, Inc. and Alexander (Zander) Berg of Fish & Richardson P.C. To summarize, Alexander (Zander) Berg inquires to IPC International as to the status of “Measuring Copper Surface Roughness for High Speed Applications” as of April 17, 2024. Logan Smith of IPC International responds as of April 25, 2024.

11. Logan Smith’s email confirms that “Measuring Copper Surface Roughness for High Speed Applications” was published in *Proceedings of the 2015 IPC APEX Expo*. Logan Smith’s email also confirms that “Measuring Copper Surface Roughness for High Speed Applications” was presented at the 2015 IPC Expo.

12. Attached hereto as Appendix IA01 is a screen capture of the Internet Archive Wayback Machine entry for http://www.ipcapexexpo.org:80/files/IPC-APEX_EXPO-2015-online-registration-FINAL4.pdf. I secured these screen captures myself from https://web.archive.org/web/20150226024618/http://www.ipcapexexpo.org:80/files/IPC-APEX_EXPO-2015-online-registration-FINAL4.pdf. This record was captured as of February 26, 2015.

13. Appendix IA01 is an Internet Archive capture of a PDF entitled "IPC APEX Expo 2015 Registration Form" as hosted on the IPC International, Inc website. Page 3 of Appendix IA01 confirms that attendees of this conference were able to purchase *Proceedings of the 2015 IPC APEX Expo*, containing "Measuring Copper Surface Roughness for High Speed Applications".

14. Attached hereto as Appendix IA02 is a screen capture of the Internet Archive Wayback Machine entry for <http://www.ipcapexexpo.org/html/default.htm>. I secured these screen captures myself from <https://web.archive.org/web/20150217035526/http://www.ipcapexexpo.org/html/default.htm>. This record was captured as of February 17, 2015.

15. Appendix IA02 is an Internet Archive capture of a web page entitled "IPC APEX Expo 2015 Home Page" as hosted on the IPC International, Inc website. This page confirms that the 2015 APEX Expo was held from February 22- 26, 2015 in San Diego, California. The conference being held from February 22 – 26, 2015 implies that "Measuring Copper Surface Roughness for High Speed Applications" was presented at the conference at some point in time between February 22 – 26, 2015.

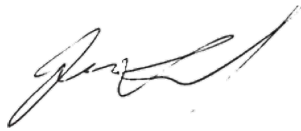
16. Appendix SMITH01 indicates “Measuring Copper Surface Roughness for High Speed Applications” was presented at the 2015 IPC APEX Expo and published within *Proceedings of the 2015 IPC APEX Expo*. Appendix IA01 indicates *Proceedings of the 2015 IPC APEX Expo* was available for purchase by conference attendees. Appendix IA02 indicates this conference was held from February 22 – 26, 2015. As such, it is my determination that “Measuring Copper Surface Roughness for High Speed Applications” was first made available to the public as of February 22 – 26, 2015 via the 2015 IPC APEX Expo and certainly no later than October 19, 2016 via the Internet Archive as represented in Appendix FRANK-WHITE01.

17. I have been retained on behalf of the Petitioner to provide assistance in the above-illustrated matter in establishing the authenticity and public availability of the documents discussed in this declaration. I am being compensated for my services in this matter at the rate of \$200.00 per hour plus reasonable expenses. My statements are objective, and my compensation does not depend on the outcome of this matter.

18. I declare under penalty of perjury that the foregoing is true and correct. I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to

be true; and further that these statements were made the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Dated: 9/12/2024

A handwritten signature in black ink, appearing to read 'June Ann Munford', with a stylized flourish at the end.

June Ann Munford

APPENDIX CV

June A. Munford
Curriculum Vitae

Education

University of Wisconsin-Milwaukee - MS, Library & Information Science, 2009
Milwaukee, WI

- Coursework included cataloging, metadata, data analysis, library systems, management strategies and collection development.
- Specialized in library advocacy, cataloging and public administration.

Grand Valley State University - BA, English Language & Literature, 2008
Allendale, MI

- Coursework included linguistics, documentation and literary analysis.
- Minor in political science with a focus in local-level economics and government.

Professional Experience

Researcher / Expert Witness, October 2017 – present
Freelance ● Pittsburgh, Pennsylvania & Grand Rapids, Michigan

- Material authentication and public accessibility determination. Declarations of authenticity and/or public accessibility provided upon research completion. Experienced with appeals and deposition process.
- Research provided on topics of public library operations, material publication history, digital database services and legacy web resources.
- Past clients include Alston & Bird, Arnold & Porter, Baker Botts, Fish & Richardson, Erise IP, Irell & Manella, O'Melveny & Myers, Perkins-Coie, Pillsbury Winthrop Shaw Pittman and Slayden Grubert Beard.

Library Director, February 2013 - March 2015
Dowagiac District Library ● Dowagiac, Michigan

- Executive administrator of the Dowagiac District Library. Located in

Southwest Michigan, this library has a service area of 13,000, an annual operating budget of over \$400,000 and total assets of approximately \$1,300,000.

- Developed careful budgeting guidelines to produce a 15% surplus during the 2013-2014 & 2014-2015 fiscal years while being audited.
- Using this budget surplus, oversaw significant library investments including the purchase of property for a future building site, demolition of existing buildings and building renovation projects on the current facility.
- Led the organization and digitization of the library's archival records.
- Served as the public representative for the library, developing business relationships with local school, museum and tribal government entities.
- Developed an objective-based analysis system for measuring library services - including a full collection analysis of the library's 50,000+ circulating items and their records.

November 2010 - January 2013

Librarian & Branch Manager, Anchorage Public Library ● Anchorage, Alaska

- Headed the 2013 Anchorage Reads community reading campaign including event planning, staging public performances and creating marketing materials for mass distribution.
- Co-led the social media department of the library's marketing team, drafting social media guidelines, creating original content and instituting long-term planning via content calendars.
- Developed business relationships with The Boys & Girls Club, Anchorage School District and the US Army to establish summer reading programs for children.

June 2004 - September 2005, September 2006 - October 2013

Library Assistant, Hart Area Public Library
Hart, MI

- Responsible for verifying imported MARC records and original MARC

cataloging for the local-level collection as well as the Michigan Electronic Library.

- Handled OCLC Worldcat interlibrary loan requests & fulfillment via ongoing communication with lending libraries.

Professional Involvement

Alaska Library Association - Anchorage Chapter

- Treasurer, 2012

Library Of Michigan

- Level VII Certification, 2008
- Level II Certification, 2013

Michigan Library Association Annual Conference 2014

- New Directors Conference Panel Member

Southwest Michigan Library Cooperative

- Represented the Dowagiac District Library, 2013-2015

Professional Development

Library Of Michigan Beginning Workshop, May 2008

Petoskey, MI

- Received training in cataloging, local history, collection management, children's literacy and reference service.

Public Library Association Intensive Library Management Training, October 2011

Nashville, TN

- Attended a five-day workshop focused on strategic planning, staff management, statistical analysis, collections and cataloging theory.

Alaska Library Association Annual Conference 2012 - Fairbanks, February 2012

Fairbanks, AK

- Attended seminars on EBSCO advanced search methods, budgeting, cataloging, database usage and marketing.

Depositions

2019 ● Fish & Richardson

Apple v. Qualcomm (IPR2018-001281, 39521-00421IP, IPR2018-01282 and 39521-00421IP2)

2019 ● Erise IP

Implicit, LLC v. Netscout Systems, Inc (Civil Action No. 2:18-cv-53-JRG)

2019 ● Perkins-Coie

Adobe Inc. v. RAH Color Technologies LLC (Cases IPR2019-00627, IPR2019-00628, IPR2019-00629 and IPR2019-00646)

2020 ● O'Melveny & Myers

Maxell, Ltd. v. Apple Inc. (Case No. 5:19-cv-00036-RWS)

2021 ● Pillsbury Winthrop Shaw Pittman LLP

Intel v. SRC (IPR2020-1449)

2022 ● Perkins-Coie

Realtek v. Future Link (IPR2021-01182)

2023 ● Fish & Richardson

Neuroderm Ltd. v. Abbvie, Inc (Case No. PGR2022-00040)

2023 ● Fish & Richardson

Nearmap US Inc. v. Pictometry International Corp. (IPR2022-00735)

2023 ● Fish & Richardson

Samsung Electronics v. MemoryWeb LLC (Case No. 39843-0136PS1)

2023 ● Pillsbury Winthrop Shaw Whitman LLP

Gravel Rating Systems v. Costco Wholesale Corp. (Civil Action No. 4:21-cv-149-ALM)

2024 ● Willkie-Farr

Netflix, Inc. v. VideoLabs. Inc. (IPR2023-00628)

Limited Case and Clientele History

Alston & Bird

- Ericsson

v. Collision Communications (IPR2022-01233)

- Nokia

v. Neptune Subsea, Xtera (Case No. 1:17-cv-01876)

- Universal Electronics Inc

v. Roku Inc (IPR2022-00818)

Arnold & Porter

- Ivantis

v. Glaukos (Case No. 8:18-cv-00620)

- Samsung

v. Jawbone (Case No. 2:21-cv-00186)

Benesch Friedlander Coplan & Aronoff

- Voyis
 - v. Cathx (Case No. 5:21-cv-00077-RWS)

Deschert LLP

- Smaxtec Animal Care
 - v. ST Reproductive Technologies, LLC (IPR2024-00885)

Erise I.P.

- Apple
 - v. Ericsson Inc. (IPR2022-00715)
 - v. Future Link Systems (IPRs 6317804, 6622108, 6807505, and 7917680)
 - v. INVT (Case No. 20-1881)
 - v. Navblazer LLC (IPR2020-01253)
 - v. Qualcomm (IPR2018-001281, 39521-00421IP, IPR2018-01282, 39521-00421IP2)
 - v. Quest Nettech Corp (Case No. 2:19-cv-00118-JRG)
 - v. Telefonaktiebolaget LM Ericsson (IPR2022-00275)
 - v. Theta IP, LLC (IPR2024-00818)

- Fanduel
 - v. CGT (Case No. 19-1393)

- Garmin
 - v. Phillips North America LLC (Case No. 2:19-cv-6301-AB-KS)

- Netscout

- v. Longhorn HD LLC (Case No. 2:20-cv-00349)

- v. Implicit, LLC (Civil Action No. 2:18-cv-53-JRG)

- Sony Interactive Entertainment LLC

- v. Bot M8 LLC (IPR2020-01288)

- v. Infernal Technology LLC (Case No. 2:19-CV-00248-JRG)

- Unified Patents

- v. GE Video Compression (Civil Action No. 2:19-cv-248)

Fish & Richardson

- Apple

- v. AliveCor (3:21-cv-03958)

- v. LBS Innovations (Case No. 2:19-cv-00119-JRG-RSP)

- v. Koss Corporation (IPR2021-00305)

- v. Masimo (IPR 50095-0012IP1, 50095-0012IP2, 50095-0013IP1, 50095-0013IP2, 50095-0006IP1, 50095-0135IP1)

- v. Neonode (Case No. 21-cv-08872-EMC)

- v. Qualcomm (IPR2018-001281, 39521-00421IP, IPR2018-01282, 39521-00421IP2)

- Dell

- v. Neo Wireless (IPR2022-00616)

- Dish Network

- v. Entropic Communications, LLC (Case No. 2:2023-CV-01043)

- v. Realtime Adaptive Streaming (Case No. 1:17-CV-02097-RBJ)
 - v. TQ Delta LLC (Case No. 18-1798)
- Evapco Dry Cooling
 - v. SPG Dry Cooling (IPR2021-00688)
- Genetec
 - v. Sensormatic Electronics (Case No. 1:20-CV-00760)
- Huawei
 - v. Bell Northern Research LLC (IPR2019-01174)
- Kianxis
 - v. Blue Yonder (Case No. 3:20-cv-03636)
- LG Electronics
 - v. Bell Northern Research LLC (Case No. 3:18-cv-2864-CAB-BLM)
- Metaswitch
 - v. Sonus Networks (IPR2018-01719)
- Microsoft
 - v. Throughputer Inc (IPR2022-00757)
- Mom Enterprises
 - v. Ddrops Company (Case No. 1:22-cv-00332)
- MLC Intellectual Property

- v. MicronTech (Case No. 3:14-cv-03657-SI)
- Nearmap Inc
 - v. EagleView Technologies (IPR2022-01009)
- Neuroderm Ltd.
 - v. Abbvie, Inc (Case No. PGR2022-00040)
- Realtek Semiconductor
 - v. Future Link (IPR2021-01182)
- Quectel
 - v. Koninklijke Philips (Case No. 1:20-cv-01710)
- Samsung
 - v. Aire Technology (IPR2022-00877)
 - v. Bell Northern Research (Case No. 2:19-cv-00286-JRG)
 - v. Communication Technologies Inc (IPR2022-01221)
 - v. Jawbone Innovations (IPR2022-00865)
 - v. MemoryWeb LLC (IPR2022-00885)
 - v. Dodots Licensing Solutions (IPR2023-00701)
 - v. Telefonaktiebolaget LM Ericsson (IPR2021-00615)
- Texas Instruments
 - v. Vantage Micro LLC (IPR2020-01261)
- Xilinx
 - v. Sentient Sensors LCC (Case No. 1:22-cv-00173)

Groombridge Wu

- Nearmap

v. Eagle View Technologies Inc. and Pictometry International Corp.
(Case No. 2:21-cv-00283-TS-DAO)

Irell & Manella

- Curium

O'Melveny & Myers

- Apple

v. Maxell (Case No. 5:19-cv-00036-RWS)

- Disney Media & Entertainment Distribution LLC

v. Digital Media Technology Holdings, LLC (Case No. 2:22-cv-01642)

- Micron Technology Inc.

v. Besang Inc (IPR2023-00900)

- Samsung

v. Daedalus Prime LLC (1335 Investigation)

Perkins-Coie

- Amazon

v. Nokia (IPR2024-00847 and IPR2024-00848)

- Heru Industries
 - v. The UAB Research Foundation (IPR2022-01148)
- Intel Corporation
 - v. BeSang Inc. (IPR2023-00991)
 - v. BitMICRO (Case No. 5:23-cv-00625)
 - v. Telefonaktiebolaget L M Ericsson (IPR2024-00610)
- Realtek Semiconductor
 - v. Future Link (IPR2021-01182)
- Twitter Inc
 - v. VOIP-Pal.com (Case No. 3:20-cv-02397-JD)
- TCL Industries
 - v. Koninklijke Philips NV (IPR2021-00495, IPR2021-00496 and IPR2021-00497)

Pillsbury Winthrop Shaw Pittman

- Intel
 - v. FG SRC LLC (Case No. 6:20-cv-00315)
- Gravel Rating Systems
 - v. Costco (Case No. 4:21-cv-149)
 - v. Lowe's Home Centers (Case No. 4:21-cv-150)
 - v. T-Mobile USA (Case No. 4:21-cv-152)
 - v. Kohl's Inc. (Case No. 4:21-cv-258)
 - v. Under Armor (Case No. 4:21-cv-356)

Quinn Emanuel

- ServiceNow, Inc.
 - v. InQuisient, Inc. (Case No. 22-900-CJB)
- Wolfspeed
 - v. The Trustees of Purdue University (Case No. 1:2021-cv-00840)

Sheppard, Mullin, Richter & Hampton LLP

- Cadence Design Systems Inc.
 - v. Semiconductor Design Technologies (Case No. 3:23-cv-01001)

Stern, Kessler, Goldstein & Fox

- Preliminary Research

Willkie, Farr & Gallagher LLP

- Neurent
 - v. The Foundry, LLC (IPR2024-00669)
- Netflix, Inc.
 - v. VideoLabs, Inc. (IPR2023-00628)

APPENDIX FRANK-WHITE01

DECLARATION OF NATHANIEL E FRANK-WHITE

1. I am a Records Request Processor at the Internet Archive. I make this declaration of my own personal knowledge.
2. The Internet Archive is a website that provides access to a digital library of Internet sites and other cultural artifacts in digital form. Like a paper library, we provide free access to researchers, historians, scholars, and the general public. The Internet Archive has partnered with and receives support from various institutions, including the Library of Congress.
3. The Internet Archive has created a service known as the Wayback Machine. The Wayback Machine makes it possible to browse more than 450 billion pages stored in the Internet Archive's web archive. Visitors to the Wayback Machine can search archives by URL (i.e., a website address). If archived records for a URL are available, the visitor will be presented with a display of available dates. The visitor may select one of those dates, and begin browsing an archived version of the Web. Links on archived files in the Wayback Machine point to other archived files (whether HTML pages or other file types), if any are found for the URL indicated by a given link. For instance, the Wayback Machine is designed such that when a visitor clicks on a hyperlink on an archived page that points to another URL, the visitor will be served the archived file found for the hyperlink's URL with the closest available date to the initial file containing the hyperlink.
4. The archived data made viewable and browseable by the Wayback Machine is obtained by use of web archiving software that automatically stores copies of files available via the Internet, each file preserved as it existed at a particular point in time.
5. The Internet Archive assigns a URL on its site to the archived files in the format `http://web.archive.org/web/[Year in yyyy][Month in mm][Day in dd][Time code in hh:mm:ss]/[Archived URL]` aka an "extended URL". Thus, the extended URL `http://web.archive.org/web/19970126045828/http://www.archive.org/` would be the URL for the record of the Internet Archive home page HTML file (`http://www.archive.org/`) archived on January 26, 1997 at 4:58 a.m. and 28 seconds (1997/01/26 at 04:58:28). The date indicated by an extended URL applies to a preserved instance of a file for a given URL, but not necessarily to any other files linked therein. Thus, in the case of a page constituted by a primary HTML file and other separate files (e.g., files with images, audio, multimedia, design elements, or other embedded content) linked within that primary HTML file, the primary HTML file and the other files will each have their own respective extended URLs and may not have been archived on the same dates.
6. Attached hereto as Exhibit B are true and accurate copies of printouts of the Internet Archive's records of the archived files for the URLs and the dates specified in the attached coversheet of each printout.

7. I declare under penalty of perjury under the laws of the United States of America that the foregoing is true and correct.

DATE: August 11, 2024

Nathaniel E Frank-White
Nathaniel E Frank-White

EXHIBIT B

https://web.archive.org/web/20161019124306/https://www.circuitinsight.com/pdf/measuring_copper_surface_roughness_ipc.pdf

Measuring Copper Surface Roughness for High Speed Applications

John A. Marshall
MacDermid Inc.
245 Freight Street
Waterbury CT, USA

Abstract

This paper examines the use of Light Interferometry and the relevant parameters used to measure copper surface roughness before and after oxide alternative. Also discussed are the limitations and drawbacks of some of the traditional measurement parameters as they apply to copper surface roughness for conductor loss and signal integrity characterization and process control.

In the PCB industry, we have seen minimal industry wide agreement on both the terminology, equipment and measurement parameter standards for the different foil types available from the copper foil and laminate suppliers. In the last 5 years, studies have indicated that high copper surface roughness is a significant factor in increased conductor losses. Specifically, the very high roughness of “Reverse Treat Foil” or “Standard Foil” whether used on the resist side or on the inner layer side was of greater significance than the micro roughness added by the oxide alternative bonding promotion treatment on the resist side.¹ Since then, the copper foil suppliers had focused on supplying copper foils with significantly reduced roughness on both sides of the foil in order to reduce high speed signal loss and preserve Signal Integrity.

The traditional “Reverse Treat” or “Double Treat” foil typically has RSAR (Roughness Surface Area Ratio) of 1.0 to 1.2, Ra of 0.7 to 0.8 microns and Rz of 8-10 microns on one or both sides of the foil. “Standard” foil typically has similar roughness on the inner layer side and RSAR of 0.3 to 0.4, Ra of 0.3 to 0.4 microns and Rz of 3-4 microns with the smooth foil on the resist side. Now we are seeing VLP (Very Low Profile) with Rz 3-4 microns and HVLP (Hyper Very Low Profile) copper foils with 2-3 microns Rz on both sides. Concurrently, we have been exploring the measurement of the “resist side” copper surface micro roughness following oxide alternative process, or bonding promotion treatment, to better understand its role in Signal Integrity and establish in-process control measurement capability.

Introduction and Background

Traditional techniques using stylus contact measurement have been typically measuring only the large peaks (macro) features, with roughness reported as Rz, or ten point height, with the total of the five highest peaks and the five lowest valleys used. Also commonly used has been PV, peak to valley or average tooth height. While still in use by some copper foil suppliers, stylus contact measurement is being replaced by non contact methods to more accurately measure the reduced copper surface roughness with $Rz < 3.0$ microns required for improved signal integrity. This paper discusses copper roughness measurements using a production white light interferometric scanning optical profiler to image and measure the micro structure and topography of surfaces in 3 dimensions, at 50X magnification with resolution capability to 0.001 microns.

The objective lens creates interference by dividing the light into two paths; directing one to an internal reference surface and the other to the test surface. Due to surface irregularities (roughness) the measurement waveform travels different distances than the reference waveform. When the two waveforms are recombined, the waves are out of phase and form an interference pattern, referred to as “fringes”. The “fringes” data is then analyzed and converted into individual pixels of roughness. Also discussed are the measurement parameters, including Rz, Ra, and RSAR that have been used to successfully measure and compare copper surface roughness before and after micro roughening with an oxide alternative to promote inner layer bonding. The initial goal was to identify the best parameters to measure the added roughness on all types of copper surfaces, including RTF, DTF, HVLP and Rolled Annealed.

Measurement Method

Initially, we had seen that the traditional parameters of Rz and Ra for roughness measurement after Oxide Alternative were adequate for measuring the added micro roughness on smooth copper, but they did not indicate the added micro roughness from Oxide Alternative roughening micro-etch when applied to an already rough RTF copper. The added roughness was

visually apparent after SEM, but Ra and Rz measurements did not appear to accurately reflect the amount of added micro roughness after Oxide Alternative. We found that RSAR was capable of measuring the copper surface micro roughness after Oxide Alternative Process with both very rough RTF copper and very smooth HVLP copper.

Through digital filtering of the test data, the surface characteristics of the test part can be broken down into waviness, roughness and high frequency results (Fig. 1). Selecting the appropriate filter settings has a significant bearing on the actual results, especially when measuring the micro roughness from the Oxide Alternative process. While the low frequency filter has shown to be very useful for removing surface waviness due to underlying glass weave impressions and any curvature of the sample, we have seen that using a high frequency filter removes a significant amount of the micro roughness that is visually apparent by SEM examination. Recently we have been using minimal low frequency filter setting of 50 and zero high frequency filter to preserve as much of the micro-roughness from the oxide alternative process as possible. The low filter setting has almost no effect on Rz, Ra, and RSAR

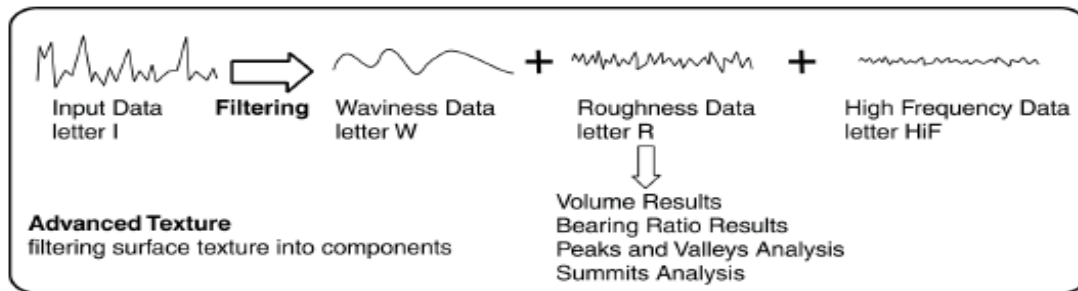


Figure 1 – Data Filtering

With many different Roughness Measurement parameters to choose from, we initially focused on three basic measurement parameters: Rz, Ra, and RSAR.

Rz, also referred to as Ten point height, is the average absolute value of the five highest peaks and the five lowest valleys, measured in microns. $R_z = (P1 + P2...P5) - (V1 = V2...V5) / 5$. (Fig. 2) We found the Rz data typically has the highest variation of all the parameters used, being influenced by any surface scratches and non-uniformity within the measurement area. Rz is useful for measuring overall **maximum** macro surface roughness, large features.

On a perfectly uniform surface, Rz would equal 10X the Ra, with higher Rz : Ra indicating increased non-uniformity.

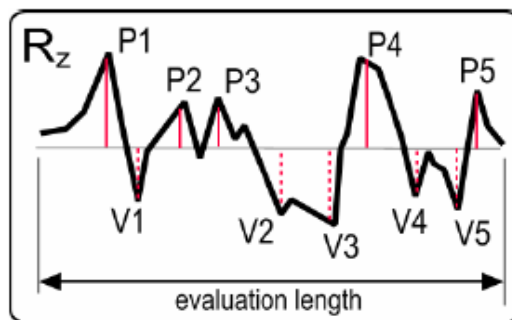


Figure 2 – Rz

Ra is defined as average surface roughness, or average deviation, of all points from a plane to fit the surface, measured in microns. On a perfectly uniform surface, the average peak to valley height would be 2X the Ra value. (Fig. 3)

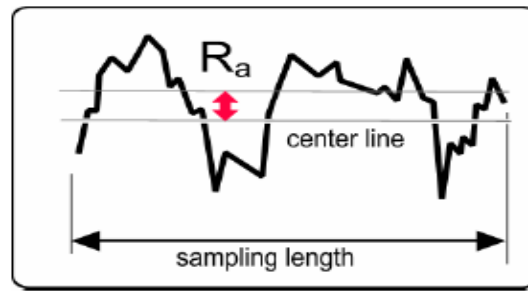


Figure 3 - Ra

Both Rz and Ra are useful to measure the macro roughness of the larger features before and after Oxide Alternative micro-etch. (Fig. 4)

RSAR is the ratio of roughness surface area to the planar area occupied by the data, as illustrated below. (Fig. 5)

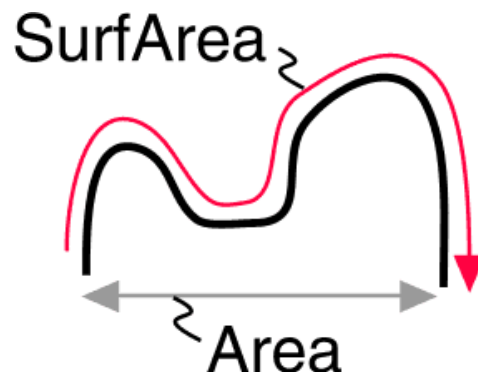


Figure 5.

RSAR measures the increase in 3 dimensional roughness relative to the 2 dimensional area it occupies and has proved to be most useful for measuring the micro roughness imparted by the oxide alternative process, especially on previously roughened surfaces including RTF copper. (Fig. 6)

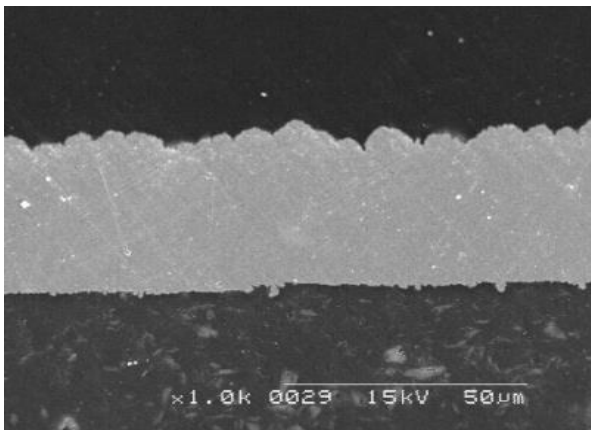


Figure 4 – Macro roughness

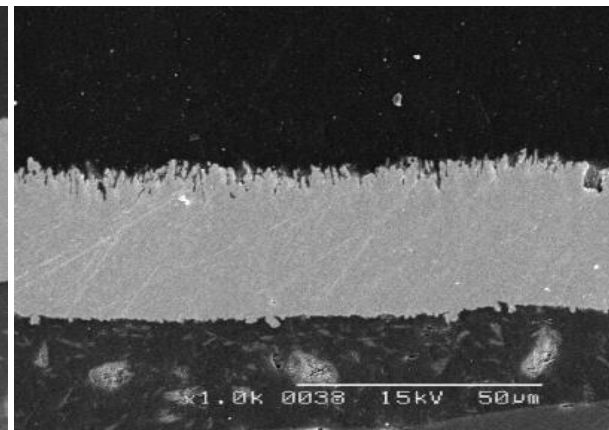


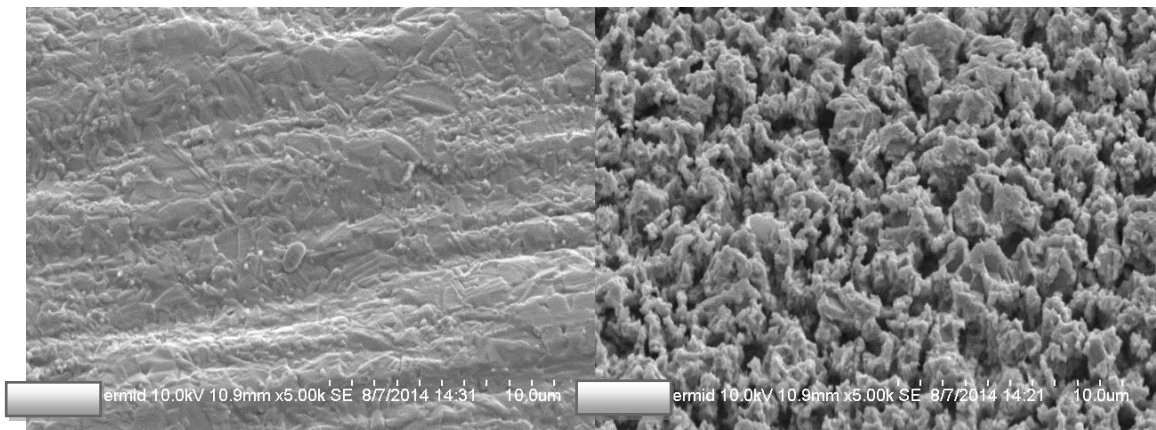
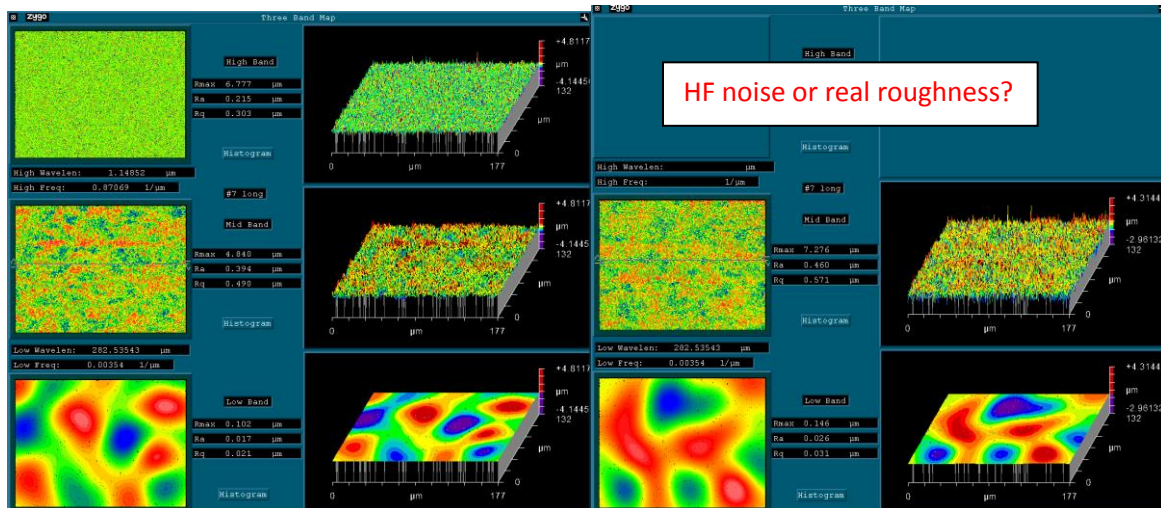
Figure 6 – Micro roughness

It was readily apparent on VLP smooth foil that all four parameters used provided accurate measurement of the increase in micro-roughness from oxide alternative. However, on RTF copper only the RSAR measurement indicated an increase (shown in green) of the micro-roughness. Interestingly, with the RTF rough copper, the Ra, Rz and Rq values were reduced, indicating some “smoothing” of the peaks through oxide alternative process. These results also indicated the negligible impact of minimum filter settings on the parameters measured, with Rz showing the biggest change. (Table 1)

Table 1 – RTF and VLP Copper

	No Filters				Filter – High 0.6/ Low 500			
RTF Cu	Ra	RSAR	Rq	Rz	Ra	RSAR	Rq	Rz
Start	1.45	1.56	1.78	11.28	1.48	1.59	1.78	11.07
After OA	1.35	2.15	1.69	11.62	1.37	1.97	1.69	10.82
VLP Cu	Ra	RSAR	Rq	Rz	Ra	RSAR	Rq	Rz
Start	0.29	0.30	0.38	3.77	0.29	0.30	0.37	3.1
After OA	0.49	1.35	0.62	8.26	0.48	1.15	0.6	6.74

Two and three Band maps of the copper surface roughness (Fig. 9 and Fig. 10) show the waviness removed by the low filter on the lower left and right scan map and the high frequency “noise” removed by the high filter on the upper left scan map. In comparison, the two band map (Fig. 10) only removed the substrate waviness and preserved all other data as “micro” roughness which compares well with the actual significant roughness observed by SEM. (Fig 11 and Fig. 12)



Samples of 6 different materials were measured by the production Light Interferometry after Develop, Etch and Strip and following Oxide Alternative process. For comparison, one sample of each material was not processed through Develop, Etch and Strip before Oxide Alternative process. The results after DES show that two of the six materials (#2 and #4) had some side to side variation in roughness. With the smooth copper, most of the variation was removed by the oxide alternative micro-etch leaving both sides with similar roughness. The RTF copper however, still had significant side to side variation after oxide alternative.

The average gain in roughness after oxide alternative oxide was calculated, with the HTE and HVLP smooth copper samples having similar results. The RTF copper sample #3 was slightly lower, while the RTF #4, with high side to side variation, had the highest increase of all samples measured. (Table 2)

Table 2 – Roughness Gain after Oxide Alternative

		Rz	Ra	Rq	RSAR
1	HTE - A	3.04	0.186	0.23	0.824
2	HTE - B	3.22	0.214	0.22	0.848
3	RTF - A	1.52	0.127	0.075	0.697
4	RTF - B	1.464	0.036	-0.03	1.2
5	HVLP - A	3.25	0.212	0.266	0.866
6	HVLP - B	2.99	0.174	0.219	0.865

During the past five years we have gained a better understanding that the very high roughness of the RTF, or “Standard” copper foil, was the most significant factor in high speed signal loss, with inner layer side roughness becoming increasingly more significant as signal speed exceeds 10 GHz.² Historically, we have seen higher variation in roughness of RTF or DSTF copper and increased roughness at higher copper weights. Overall, the Signal Integrity results have reversed the trend towards RTF copper for increased bonding integrity following the conversion to “lead free” assembly conditions. With that understanding, we have seen new copper foil products introduced with significantly reduced roughness on both the inner layer side and the resist side.³ (Table 3)

There has been a growing trend away from the “standard” RTF copper found on both sides of the foil. Many customers have been successful in producing PCBs with up to and above 13 GHz by careful choice of the appropriate material combined with low profile copper foil and reduced oxide alternative etch rate. We have also seen that controlling the etch rate and the chemical conditions in the oxide alternative process are critical in maximizing conductor profile and in reducing the conductor roughness to optimize signal integrity. PCB fabricators are now focusing more on the “resist side” copper starting roughness, in-process micro-etch and “fine tuning” the conductor roughness after oxide alternative bonding promotion treatment.

Table 3 – Typical Inner Layer Resist Side Roughness

Resist Side	Ra	RSAR	Rq	Rz
STD (RTF)	0.6 - 1.5	0.7 - 1.5	1.0 - 2.0	7.0 - 12.0
VLP (HTE)	0.3 - 0.35	0.3 - 0.4	0.3 - 0.4	3.0 - 4.0
HVLP	0.25 - 0.3	0.2 - 0.3	0.25 - 0.35	2.0 - 3.0
After Alt. Oxide	Ra	RSAR	Rq	Rz
STD (RTF)	0.7 - 1.4	1.2 - 2.2	1.0 - 2.0	7.0 - 12.0
VLP (HTE)	0.45 - 0.6	0.8 - 1.5	0.6 - 1.0	6.0 - 8.0
HVLP	0.4 - 0.5	0.7 - 1.3	0.5 - 0.7	4.0 - 6.0

Measurement Parameter Limitations

With a wide choice of parameters available for conductor surface roughness measurement, we find the most effective are: Rz to define maximum roughness, RA to define overall average macro roughness and RSAR to define the micro-roughness from the oxide alternative process. However, as we saw when measuring micro-roughness on previously roughened copper, there would appear to be limitations with utilizing some of those measurement parameters into signal loss predictions, especially in surfaces with non-homogenous roughness.

While Ra provides a good description of the average roughness of a uniform surface it does have some limitations as shown below. These two examples below have the same Ra, but not the same conductor length and not the same RSAR. They could well have different signal losses, depending on signal frequency and the actual circuit dimensions. (Fig. 13)

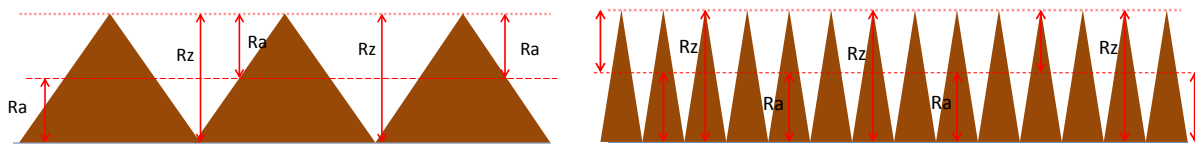


Fig. 13 - These Surfaces have the same Ra and the same Rz

Rz measurements typically have greater variation than other parameters, due in part to the measurement of only the five highest peaks and the five lowest valleys. Rz measurements are influenced by surface scratches and typically have the highest variation. All the surfaces shown have the same Rz, but not the same surface length. (Fig 14)

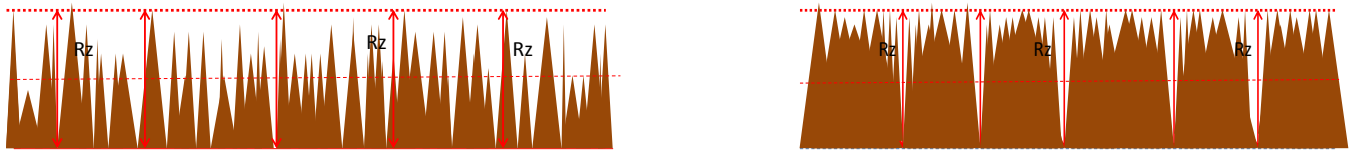


Fig. 14 – These surfaces have the same Rz

Conclusions

We have found that using Light Interferometry Surface Roughness Measurement provides Ra, RSAR and Rz measurements for controlling inner layer copper roughness before lamination to assure in range condition of pre-established conductor losses. RSAR is the most useful for providing accurate data of the smaller (micro roughness) features imparted by the oxide alternative process or other chemical roughening processes and Ra measurements provide accurate data of the larger (macro roughness) features. Rz measurement only shows the maximum surface roughness and can be somewhat misleading, having sensitivity to any scratches or surface defects. However Rz is helpful in assessing overall non-uniformity by the relationship with Ra. Additionally, Rz can be measured by cross-section of the inner layer side of the foil to provide an “As received” record of the previously laminated foil side.

We have seen the correct preparation (grinding and polishing) of cross-sections to be critical in obtaining reasonably accurate Rz numbers of the macro-roughness. Determination of the gain in surface roughness through Oxide Alternative process, before lamination, can provide process control data through the process. Additionally, the program provides Standard Deviation and Coefficient of Variation % data for SPC. Analyzing the raw measurement data with no reduction in micro roughness from high frequency filtering and minimal low filtering, provides accurate, optimized measurements of the copper surface. RSAR and Ra together provide an accurate measured representation of the micro roughened copper surface following Oxide Alternative Process and are suitable for process control.

References

1. Effect of Conductor Surface Roughness upon Measured Loss and Extracted Values of PCB Laminate Dissipation factor. Scott Hinaga, Cisco Systems Feb 2, 2010.
2. Insertion Loss Reduction through Non-Roughening Inner layer Surface Treatment. Scott Hinaga, Cisco Systems, March 25, 2014.
3. Signal Transmission Loss due to Copper Surface Roughness in High Frequency Region. Elaine Lew, Mitsui Copper Foil Malaysia.

APPENDIX SMITH01

Subject: RE: IPC Apex 2015 Proceedings
From: IPC <contact.us@ipc.org>
Date: 4/25/2024, 10:16 AM
To: Zander Berg <berg@fr.com>

[This email originated outside of F&R.]

Hello Zander,

Thank you for reaching out to us. We unfortunately no longer have the 2015 proceedings and schedule available. However, I can confirm that this paper was presented at IPC's 2015 APEX EXPO and the paper was published in the 2015 APEX EXPO proceedings.

Please let me know if you have any questions.

Best regards,

Logan Smith
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To: Contact.us@ipc.org
Subject: IPC Apex 2015 Proceedings

Hello,

I'm a patent agent at the law firm Fish & Richardson, currently working on a project involving copper foils. I'm wondering whether you have a copy of the proceedings or schedule of IPC APEX 2015? Specifically, I'd like to confirm that "Measuring Copper Surface Roughness for High Speed Applications" (John A. Marshall) was published or presented at that conference. A copy of the paper is attached here.

I would be grateful for any information you could offer.

Thanks,

Zander

Alexander Berg, Ph.D. :: Technology Specialist, Patent Agent :: Fish & Richardson P.C. :: he/him
(212) 641-2232 direct :: berg@fr.com

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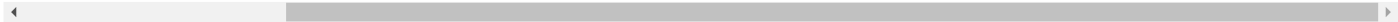
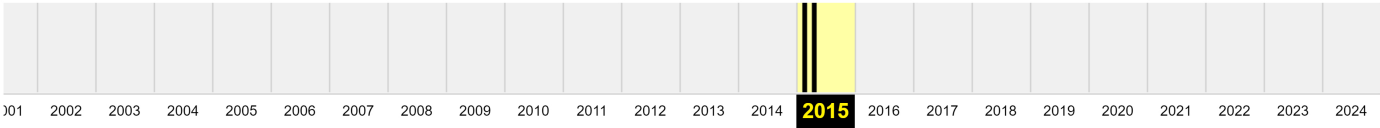
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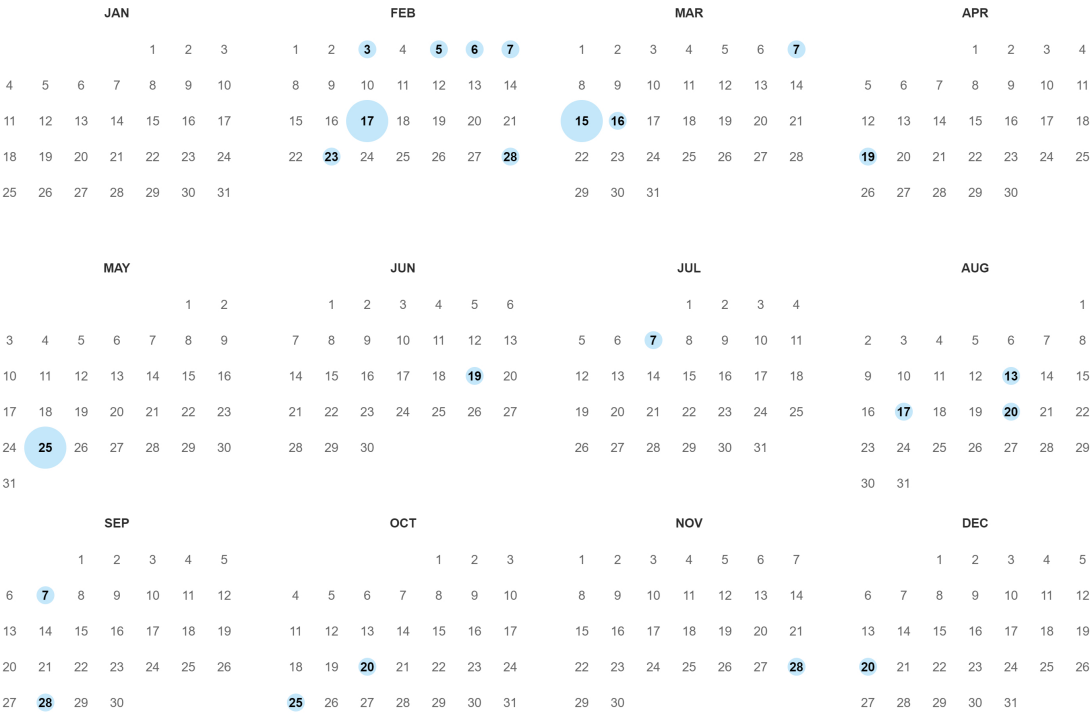
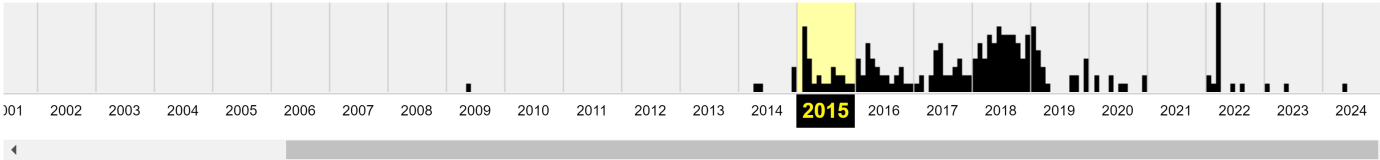
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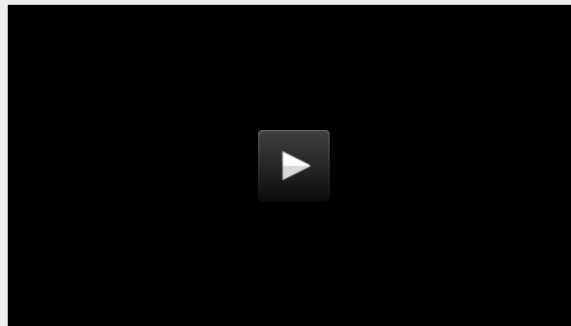
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... watch this short video for a preview of IPC APEX EXPO 2015, and watch this site for the latest event information as it is announced.



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Keynotes



Robbie Bach
Former President of
Entertainment & Devices at
Microsoft, Xbox Visionary &
Civic Activist



Stanton Friedman
Nuclear Physicist & Lecturer
Wednesday, February 25
9:00 am – 10:00 am

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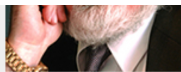
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"We truly believe that
this technology will not
only change the way
that boards are
manufactured, but
designed, for us and
the entire industry."

Andrew Murrietta
CEO of Murrietta Circuits,
eSurface licensed



Tuesday, February 24
8:30 am – 9:30 am



The Xbox saga – from garage-shop inception, through numerous crises and challenges, to ultimate business success – is a multi-faceted tale with several fascinating story lines. Robbie Bach, who will speak from his experience as the Chief Xbox Officer, will join us at IPC APEX EXPO 2015 to take us behind the scenes.

Friedman will challenge IPC APEX EXPO 2015 attendees as he draws on more than 40 years of research on UFOs, and his work on a wide variety of classified advanced nuclear and space systems. He will answer a number of physics questions in layman's terms, and establish that travel to nearby stars is within reach without violating the laws of physics. [Learn more...](#)

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IPC is a global trade association dedicated to furthering the competitive excellence and financial success of its members, who are participants in the electronics industry. In pursuit of these objectives, IPC will devote resources to management improvement and technology enhancement programs, the creation of relevant standards, protection of the environment, and pertinent government relations.

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About IPC APEX EXPO

IPC APEX EXPO 2015 is a five-day event like no other in the printed circuit board and electronics manufacturing industry. Professionals from around the world come together to participate in the Technical Conference, Exhibition, and Professional Development, Standards Development and Certification programs. These activities offer seemingly endless education and networking opportunities that impact your career and company by providing you the knowledge, technical skills and best practices to address any challenge you face.

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