Verification of Electrical Grounds/Bonds Using Computer Vision

A Technical Paper prepared for SCTE•ISBE by

Shawn Kercher
Principal Engineer
Comcast Innovation Labs
4100 E. Dry Creek Road, Littleton, CO
Shawn_Kercher@comcast.com

Jacob Hallberg
Software Development Engineer
Comcast Innovation Labs
4100 E. Dry Creek Road, Littleton, CO
Jacob_Hallberg@comcast.com

Table of Contents

Title **Page Number**

List of Figures

Title **Page Number**

1. Introduction & History

Electrical grounding and bonding, as a means to provide a low-impedance electrical connection between two or more metallic bodies that are normally not current-carrying, has long been a necessary task for the industry. Electrical groudning prevents circuit overloads and removes dangerous ground-fault voltage on conductive parts. Primarily, grounding and bonding is a mechanism to protect homes and businesses, and their contents (including people), from electricity surges, such as from lightning.

When all of the communication and power grounds are working at a home or business, and are all "good grounds," any stray current in the system goes to ground and no voltage differences exist between themwhich is the desired state. However, when grounds are bad, the current can and will find its way into the CATV network. When voltage appears in the CATV network the voltage potential problem appears to "drop the voltage" of anything connected to the network. Set-top boxes, modems, gateways, or, in the case of large MDUs, line extenders all have seen the drop in voltage. Stories abound from technicians taking the hit of 90-volt shocks from power-passing taps, or 120-volt shocks when hooking cable up to taps in MDU lockboxes – which makes for a decidedly unpleasant site visit! Proper electrical grounding and bonding is as equally or more important to business/enterprise customers especially when lightning hits a facility, knocks out half of its servers, and turns out to be a grounding issue – as in, "our fault" (pun intended.)

This paper describes the use of Computer Vision (CV), Artificial Intelligence (AI) and Machine Learning (ML) to provide technicians with a visual verification that gives them a high level of confidence that the structure (the home or business) they're visiting is properly grounded and bonded, using an app developed at Comcast Labs, on their work-issued iPhone or iPad. The paper covers the background and history of grounding and bonding; why those activities continue to be vitally important in communications network performance; and the importance of images and image annotation to build a production-grade database of proper grounds/bonds that can be put to work by field technicians when assessing a home or business.

1.1. A Brief History of Electrical Grounding and Bonding

While electrical grounds and bonds have been overseen since the late 1960s by entities like the National Electrical Code (NEC), in part 820 [1], compliance reporting is generally not a requirement. Unlike rules like Cumulative Leakage Index (CLI), which require quarterly compliance reports, the job of making sure the ground/bond is true is voluntary and not enforced. That said, some cities and franchise authorities have instituted grounding and bonding inspections, to monitor how many jobs are properly grounded and bonded. Improper grounding/bonding in those instances have incurred fines, which is to say it also impacted profits.

Our work to automate the inspection process for proper grounds and bonds began as an offshoot of a related project, which uses CV, ML and AI to catalog the contents of racked equipment in data centers. The intent was to automate regular equipment inventories and establish a visual map of where servers are, physically, in what can be large and cavernous facilities full of such gear. Late in 2019, we were approached with the idea of extending the effort towards outside plant activities, in particular, helping technicians to verify that the electrical ground is good. Considering the fact that electrical grounding activities began before WWII, and that the U.S. counts roughly 125 million homes (a number that does not include businesses), the range and types of electrical bonds we encounter are vast. Countless (and uncounted) variations exist in the field. Hence the importance of training data and the establishment of a solid visual database to catalog existing manners of grounds and bonds.

2. Job #1: Images & Training Data

The reason why we're talking about good electrical grounds and bonds in the year 2020 is the as network operators we are responsible for the safety of our technicians, customers, their homes/businesses, and the electrical devices within those homes and businesses. Merely through expectations and the accountability that we take each day, in connecting customers to our network, the electrical ground and bond is a vital, if sometimes overlooked, activity. After spending the last decade stabilizing the major portions of the network – platforms, headends, CMTS devices, outside plant components – another domino in the lineup, in the pursuit of overall network reliability, is grounding and bonding.

This effort started by developing an app, accessible on an iPhone, iPad or web browser, with linkages to images of about 30 grounding/bonding implementations encountered in the field. The app was given to roughly 50 employees, at the start, to capture and ultimately catalog a visual database. These employees were spread out over the United States, giving us a varied dataset of 1,500 bonding and grounding images. This varied dataset helps combat the identification problem of the many different types of grounds and bounds that stem from WWII-era home construction onwards.

In order for the system to be production-gradefrom a Computer Vision perspective, substantially more training images will be required – as many as 10,000 or more. This estimate can be drastically increased if proper selection of images is not taken. For example, the bonding hardware, the bond block, and filters can all vary in appearance depending on the region of the country and when the home was built. This data variance makes it harder for the system to learn all of the different types of bonding and grounding hardware it will see in the field. Consequently, if not addressed correctly, the system will require additional training images to be production-grade.

The visual database is split into two categories: house box and power bond. The house box category generally consists of a frontal shot of a house box. The house box is in most cases mounted to the side of the home and houses the bond block and the Multimedia over Coax Alliance (MoCA) filter (see Figure 2). The power bond category generally consists of many differently angled shots that capture the bonding hardware (see Figure 4). Categorizing the images in the visual database into these two categories is an essential part of training a production-grade system. It allows the system to learn the specificities of each category, improving accuracy and robustness.

Currently, our bonding and ground AI uses approximately 1,000 house box images and 500 power bond images to train the system. Using machine learning techniques called Transfer Learning, Data Augmentation, Regularization, and Semi-automated Image Selection, we are able to drastically reduce the total number of images needed for training. Based on our current rates of accuracy for both power bond and house box, we estimate we'll need upwards of 10,000, or more training images to release a production-ready system.

Figure 1 - A selection of images from the House Box category

Figure 2 - Image example of House Box category; panels 2 and 3 highlight the bond block and filter, respectively

Figure 3 - A selection of images from the Power Bond category

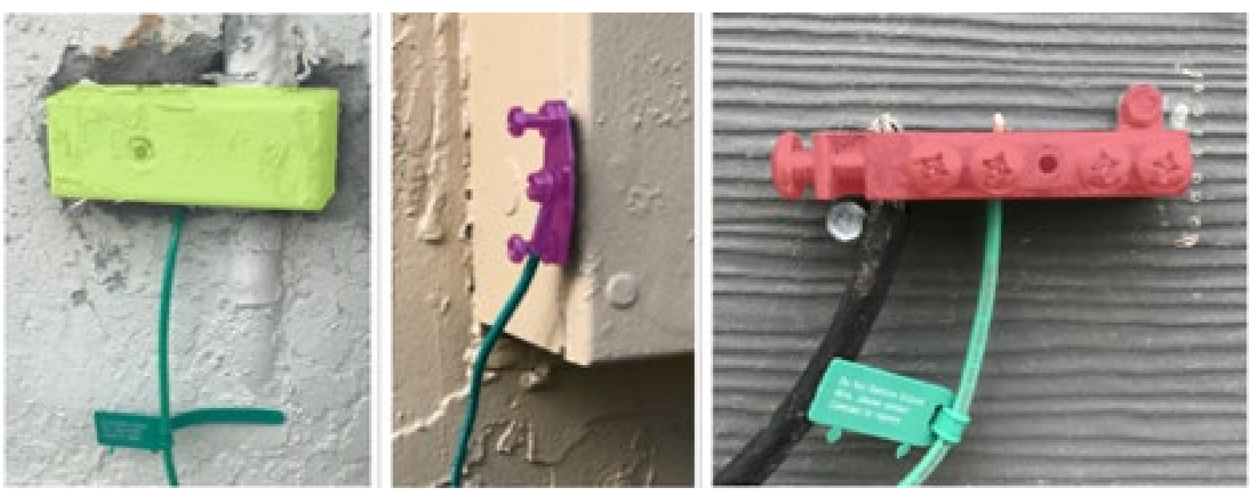

Figure 4 - Each panel shows the bonding hardware highlighted

3. The Other Job #1: Annotating Images

Once the visual database is established, and growing, a corollary and vital task is image annotation – to manually mask the objects of interest within an image. As important as the image itself, image annotations are the backbone of training a Computer Vision system. Annotation requires a person to open the image in an image annotation tool and "mask over" the object of interest with a polygon shape (see Figure 5). All pixels within the polygon shape are then labeled to correspond to the object of interest. In bonding and grounding, the objects of interest are the bonding hardware, bond blocks, and filters. Note the points that make up the polygon mask. All pixels within this mask are deemed to correspond to the filter object for this specific image, which is used to train the Computer Vision system.

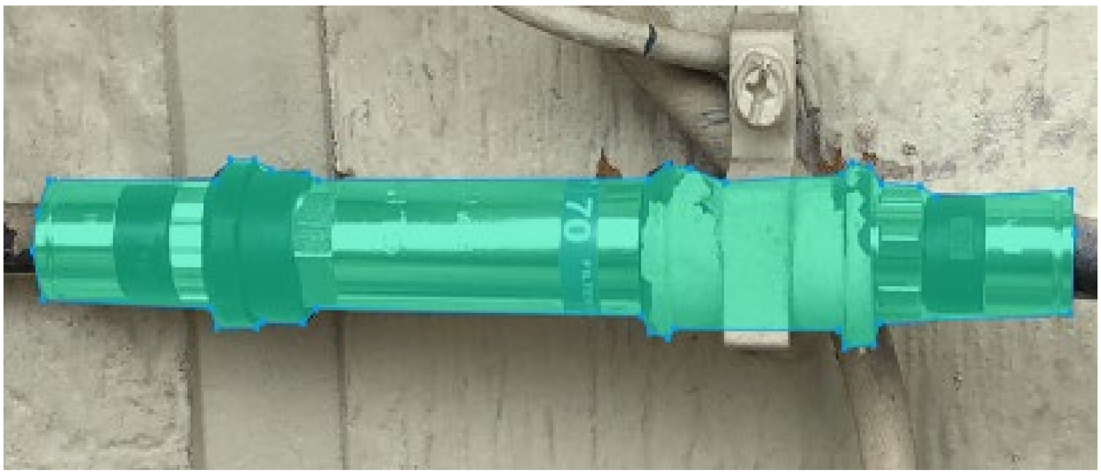

Figure 5 - Example annotation of a House Box filter object of interest

This annotation job must be done for each and every image that enters the visual database. Additionally, each annotation must be checked for accuracy, to ensure that any bad annotations do not negatively affect the accuracy of the system. After the images in the visual database have been annotated, and their annotations verified, they are finally ready to be shown to the Computer Vision system to learn the intricacies of the object.

To ease the burden of annotation, we made use of active learning (see Figure 6). Active learning is the process of training our Computer Vision system, first with a small subset of labeled images, and then using the system's learned ability to decide which new subset of images in the visual database should be annotated manually. We then annotated the new subset of images from the system manually, and repeated the process. This process of human-machine iteration is essential to reducing the cost of annotation, and overall improves the end result of system.

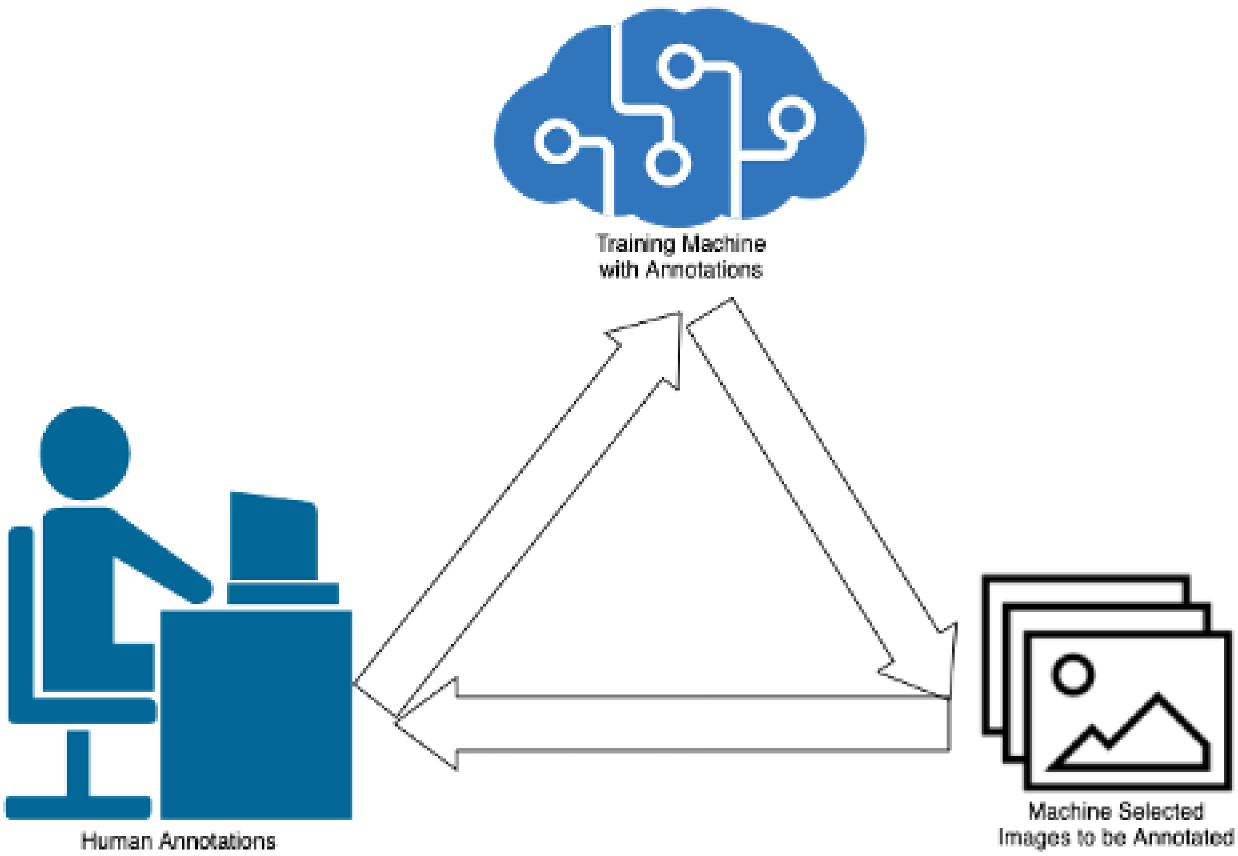

Figure 6 - An active learning pipeline to reduce costs (time and money) of image annotations

4. The App & How It Works

To approach the job of creating a Computer Vision-enabled means of visually verifying electrical grounds and bonds, we built two apps: a WebApp and an iOS App. Both use the same API endpoint to upload images to be inferenced to the Computer Vision model. This process leverages GPUs for detecting Filters and Ground Bonds. The CV model is coupled on what it detects, using rules to determine if a filter and ground block is wired correctly. Each image is captured, saved to our database and added to the ML training data. A feedback section indicates whether or not the CV model detected the image correctly.

Rules were developed to determine a simple validation for the house box and the power bond, as characterized below:

House Box
- Does a filter exist?
- Does a bond block exist?
- Bond block connected to filter?

Power Bond
- Does a tag exist?
- Does bonding hardware exist?
- No prohibited bonding locations?

Steps:
1. Snap a picture or upload an image of the House Box or Power Bond
2. Receive an answer if Ground Bond/Filter is properly installed

4.1. WebApp Version

This version was built specifically to run on a phone browser. We started with a WebApp to iterate quickly. This tool can be exceptionally valuable for testing (see Figure 7.)

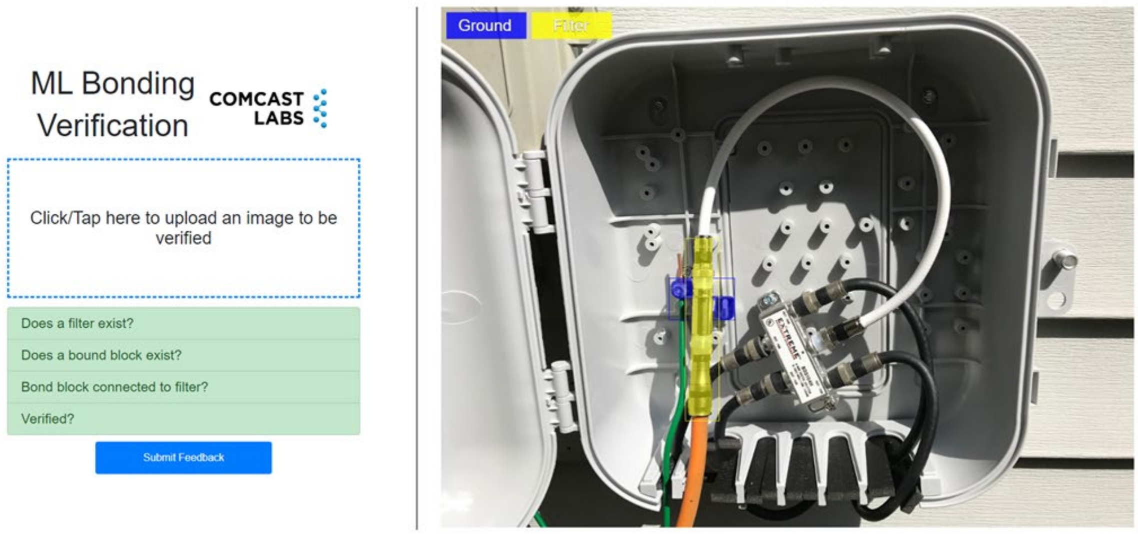

Figure 7 - A view of the WebApp version for Computer Vision grounding/bonding

4.2. iOS App

Our vision for building an iOS app was to make the user experience as smooth and easy as possible. This app makes it easy for users to point, click, and view results in a very user-friendly way (see Figure 8).

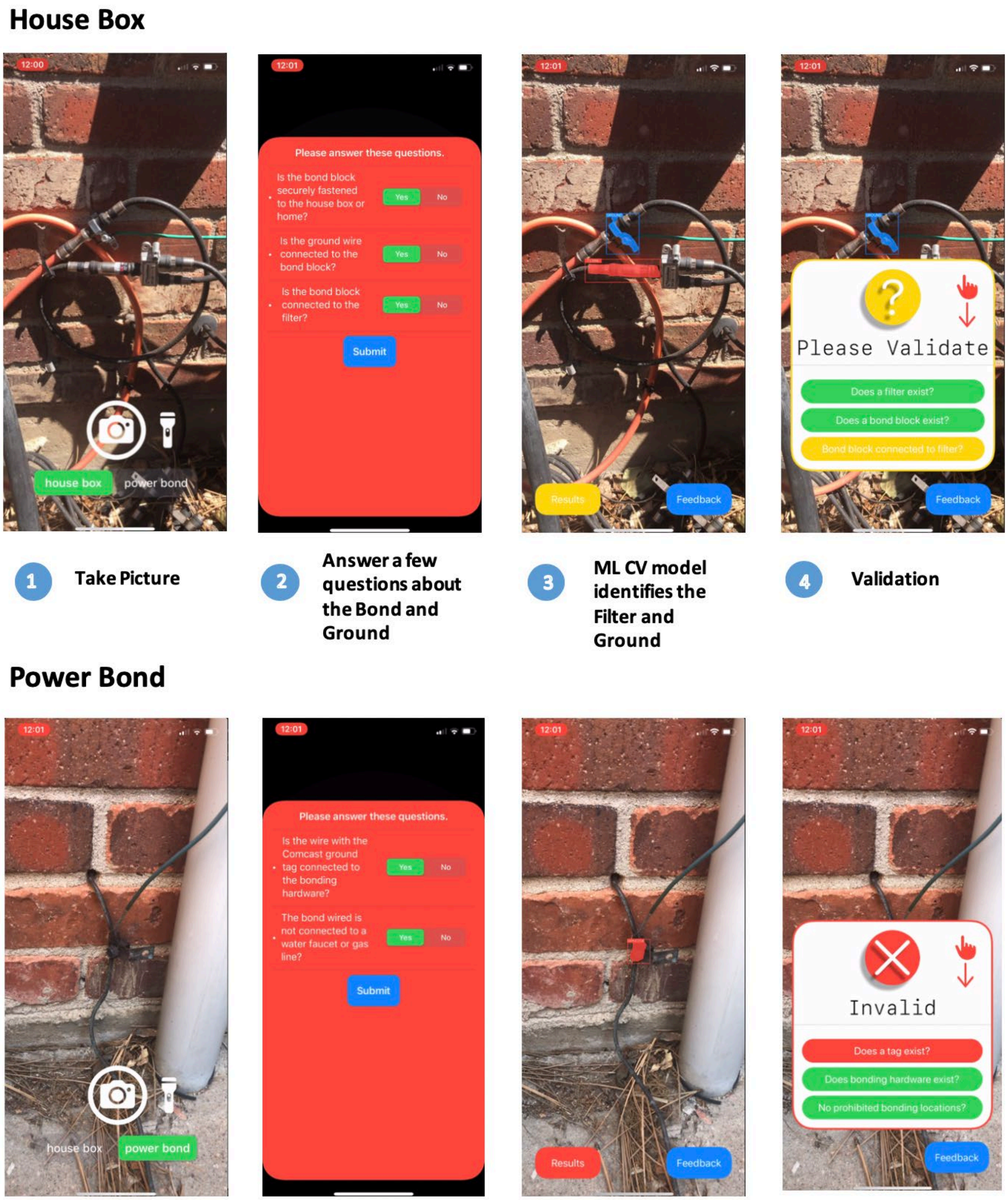

Figure 8 - A view of the iOS app for Computer Vision grounding/bonding

4.3. Trial

The Computer Vision app for electrical grounding and bonding verification is currently in trial in all three Divisions of Comcast, and specifically in systems within our Georgia, Florida and Colorado footprint. The app was successfully deployed to 50+ technician iPhones, used by technicians who are participating in the trial. So far, our feedback and learnings have been crucial to gain knowledge on how technicians are using the app, and to interpret different use cases we have not seen before.

Next steps are to integrate the app with an internally-developed digital tool, developed by and for technicians, called "Tech 360," and designed to give them a 360-degree diagnostic view of the homes and businesses they visit. That work is slated to be complete by year-end 2020, with anticipated availability to our 35,000+ techs by the middle of 2021.

4.4. Future updates

As the Computer Vision app expands in reach and usage, we are compiling a list of desired feature additions for the WebApp and iOS app. The list below represents a partial summary:

- *Development of an Image Queue*: If no mobile or WiFi network is available, enable the app to cache the images, then retry when connectivity resumes
- *Ease connection procedure:* Implement SSO and remove VPN
- *Implement wire tracing:* This will evaluate both RF and ground wires to ensure they are properly attached
- *Implement logic:* To determine if bond block is attached to the house box
- *Increase usability:* Add flags and notifications
- *Increase distinguishability:* Implement the ability to distinguish between six different filters that are deployed in the field.

5. Conclusion

Assuring the existence of a proper electrical ground and bond is a vital and longstanding best practice in cable telecommunications and broadband networks. What makes the task challenging is the simple fact that electrical grounds and bonds date back to the earliest days of homes with electricity. They're necessary to provide low-impedance electrical connections between two or more metallic bodies that are normally not current-carrying, to prevent circuit overloads and remove dangerous ground-fault voltage on conductive parts.

Good grounds mean that any current in the system goes to ground, and no voltage differences exist between them. Bad grounds can create voltage potential problems that appear to "drop the voltage" of anything connected, whether set-top boxes, modems, gateways, or, in the case of large MDUs, line extenders. Bad grounds can also wreak havoc when lightning strikes.

This paper described the use of Computer Vision, Artificial Intelligence and Machine Learning to provide technicians with a visual confirmation, intended to give them a high level of confidence about the ground andbond of a home or business. Using a WebApp and iOS app developed at Comcast Labs' Denver-area facility, technicians can verify grounds andbonds on their work-issued iPhone or iPad. It covers the background and history of grounding and bonding, why those activities continue to be important in communications network performance, and a discussion of the image collection and annotation necessary to build a production-grade visual database of proper grounds andbonds. This effort is in trial now (summer 2020), with plans to integrate this technology into a core digital diagnostics app used by field technicians following a successful trial.

Abbreviations

AI	Artificial Intelligence
CATV	Cable Television
CLI	Cumulative Leakage Index
CMTS	Cable Modem Termination System
CV	Computer Vision
GPU	General Processing Unit
MoCA	Multimedia Over Cable Alliance
MDU	Multiple Dwelling Unit
ML	Machine Learning
NEC	National Electrical Code
RF	Radio Frequency
SSO	Singal Sign On
VPN	Virtual Private Network

Bibliography & References

[1] National Electrical Code, Article 820: Community Antenna and Radio Distribution Systems: https://www.ecmweb.com/national-electrical-code/code-basics/article/20885527/article-820-community-antenna-tv-and-radio-distribution-systems