Stray Voltage Investigation

by Vitatech Electromagnetics, LLC

Sponsored by

National Regulatory Research Institute (NRRI)
www.nrri.ohio-state.edu
The Ohio State University
Columbus, Ohio
Ray Lawton, Director
Robert Burns, Electric Research

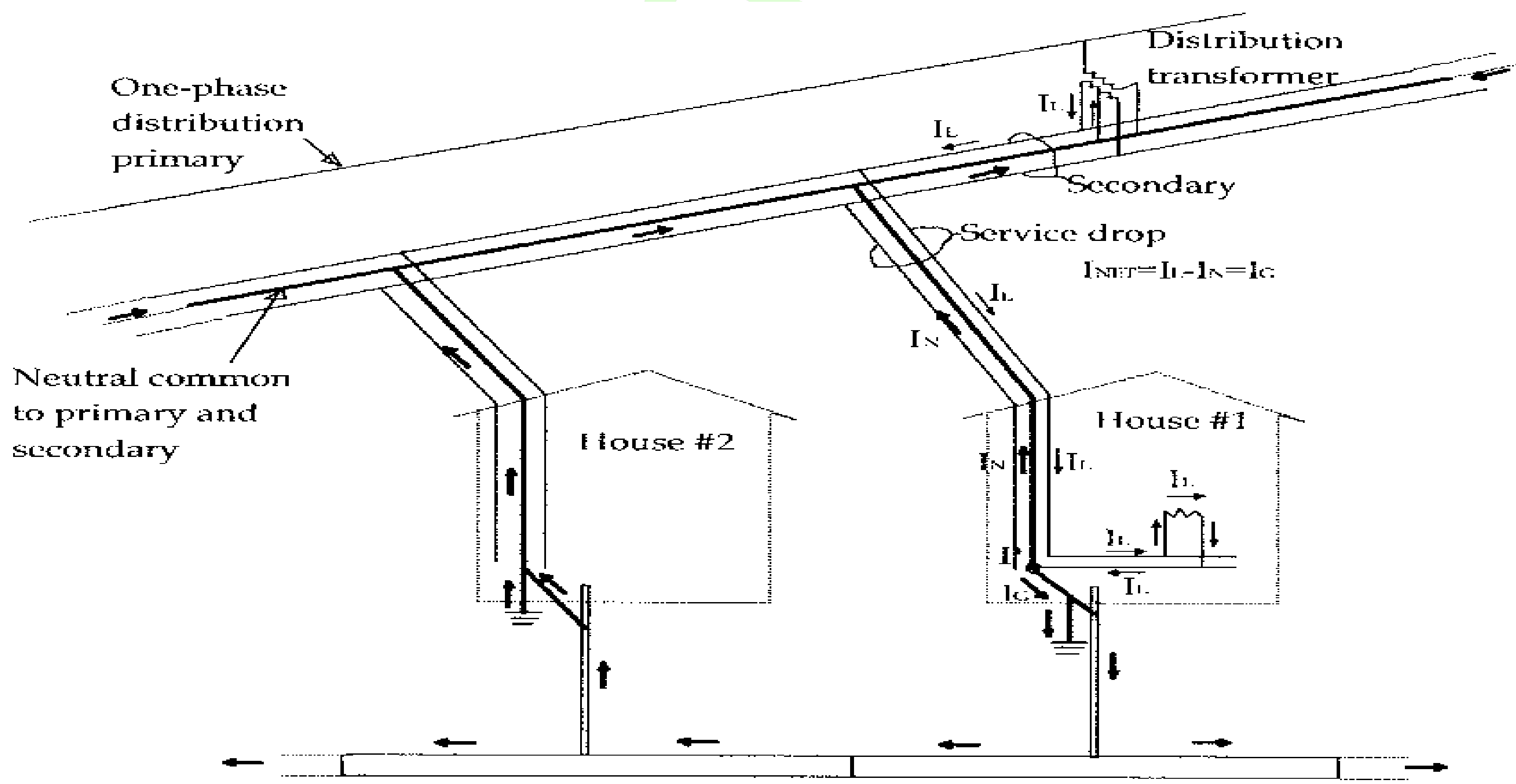
Initial Meeting & Information

9 October 2002

- JCP&L provided project history & test info
  - Initial Stray Voltage compliant 22 July 2002
  - Standard troubleshooting/fixed some problems
  - Implement vigorous program to fix problem
  - Reconductored Driscoll neutrals: 10 V to 5 V
  - Installed new ground rods & down grounds
  - NJ State geological survey - high resistivity soil
  - test showed reduction in load lowers NEV
  - JCP&L offered full cooperation and access to Vitatech

Perceived Stray Voltage Events & Causes

In July 2002 during the peak summer load and *exceptional drought* conditions several JCP& L customers adjacent to the Herbertsville Substation on Driscol and Frede Drives in the Town of Brick, New Jersey, reported *tingling sensations* known as *stray voltage* while touching their pools, Jacuzzis, outdoor showers and other conductive objects. Testing revealed the problem still persisted with the main electrical panels de-energized (breakers or fuses open) indicating the stray currents (the cause of stray voltages) appeared to enter each residence from the utility pole via the overhead secondary service neutral conductor, which is bonded to the neutral-ground bus in each main electrical panel. Also grounded to the neutral-ground bus are the metallic water service pipe, ground rod, CATV and telephone drops (see diagram below for pictorial representation).



Ground Currents Caused by Residential Loads in a Typical Situation

Perceived Stray Voltage Events & Causes

On the utility poles the overhead secondary service neutrals are bonded to the primary neutrals, down-grounds and ground rods, CATV and telephone cable guy wires. Under normal seasonal conditions with ample rain and low soil resistivity, the primary neutral currents (known as zero-sequence currents because of the unbalanced phasing) return to the substation via the overhead primary neutral conductors and underground earth channels (composed of conductive layers of soil). Normally, earth channels return a significant portion of the primary neutral currents, which enter the underground earth channels from the pole down-ground rods, and metallic water service laterals/mains that meander under the front yards, sidewalks and streets.

The Herbertsville substation and adjacent neighborhoods “showed uniform geology in the area of concern….fine to coarse quartz sand with quartz-pebble” according to the NJGS. Since sandy soil normally has high resistivity, during the 2002 drought, the existing earth channels quickly disappeared as the water table (saturation zone) retreated forcing significantly more primary neutral current to return to the substation via the overhead primary neutrals. This additional primary return current increased the voltage potential (difference) between the substation ground (now electrically isolated from the adjacent neighborhoods due to the exceptional drought and sandy conditions) and the multi-grounded primary neutral (MGN) distribution systems in the adjacent neighborhoods. The consequence was an increase in neutral-to-earth voltages (NEV) on the pole down-grounds and grounded-neutrals in the main electrical panels within homes near and adjacent to the Herbertsville substation.

Herbertsville Substation

- Two 34.5 kV sub-transmission lines
- 25 MVA Transformer Bank #1 - Circuits 82 & 83
- 20 MVA Transformer Bank #2 - Circuits 80 & 81
- Upgraded Circuits 82 & 83 from 4.8 kV delta
- Primary Feeder Sizes: 397AA
- Neutral Feeder Sizes: Mix #2 ACSR and #2/0 AA
- Bank #2 Added 500 MCM Neutral From X0 bushing to Switchgear Neutral – No change in NEV

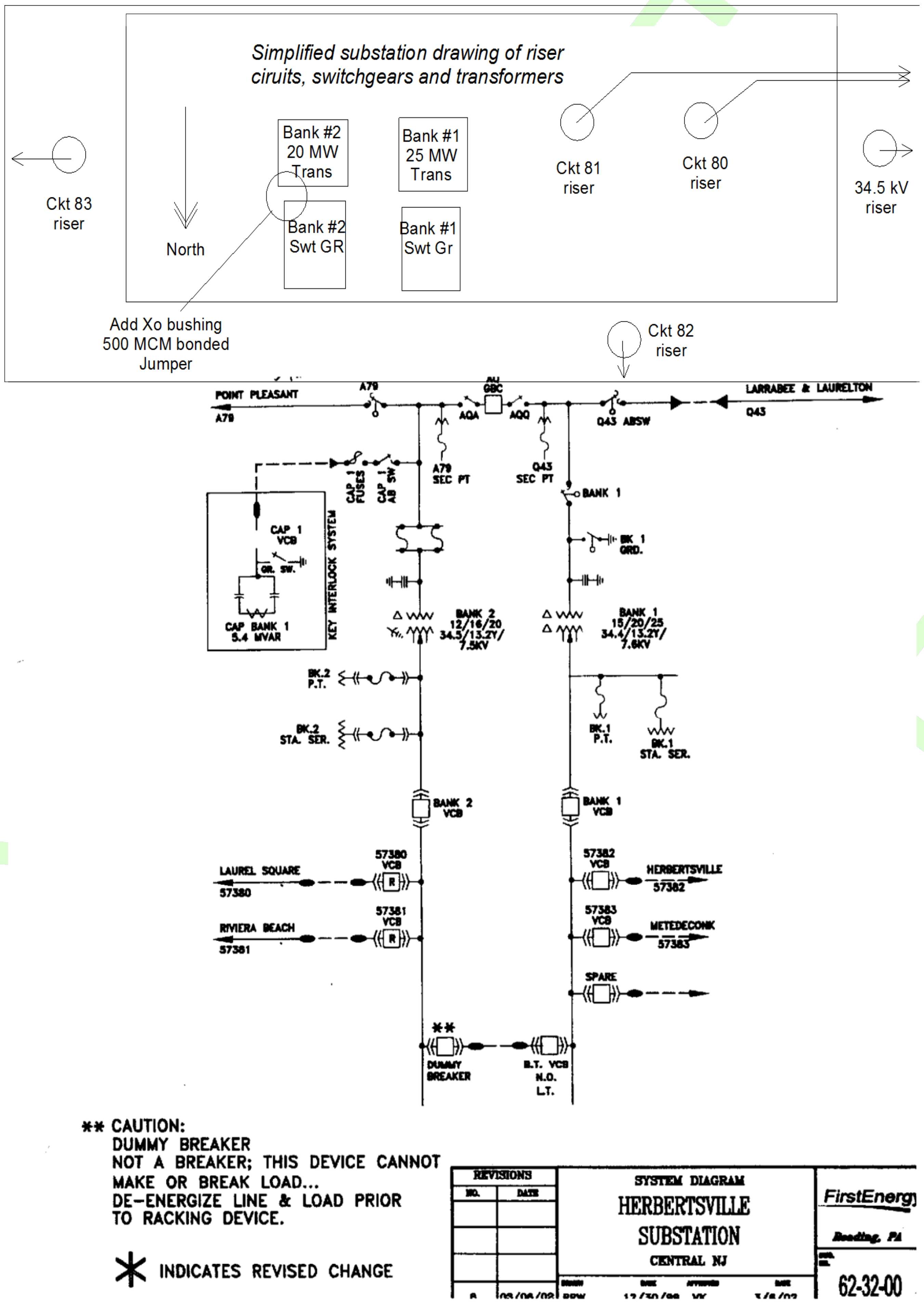


Figure #1, Herbertsville Substation Single Line Diagram

Herbertsville Substation Looking Eastward Circuit 83 & 34.5 kV

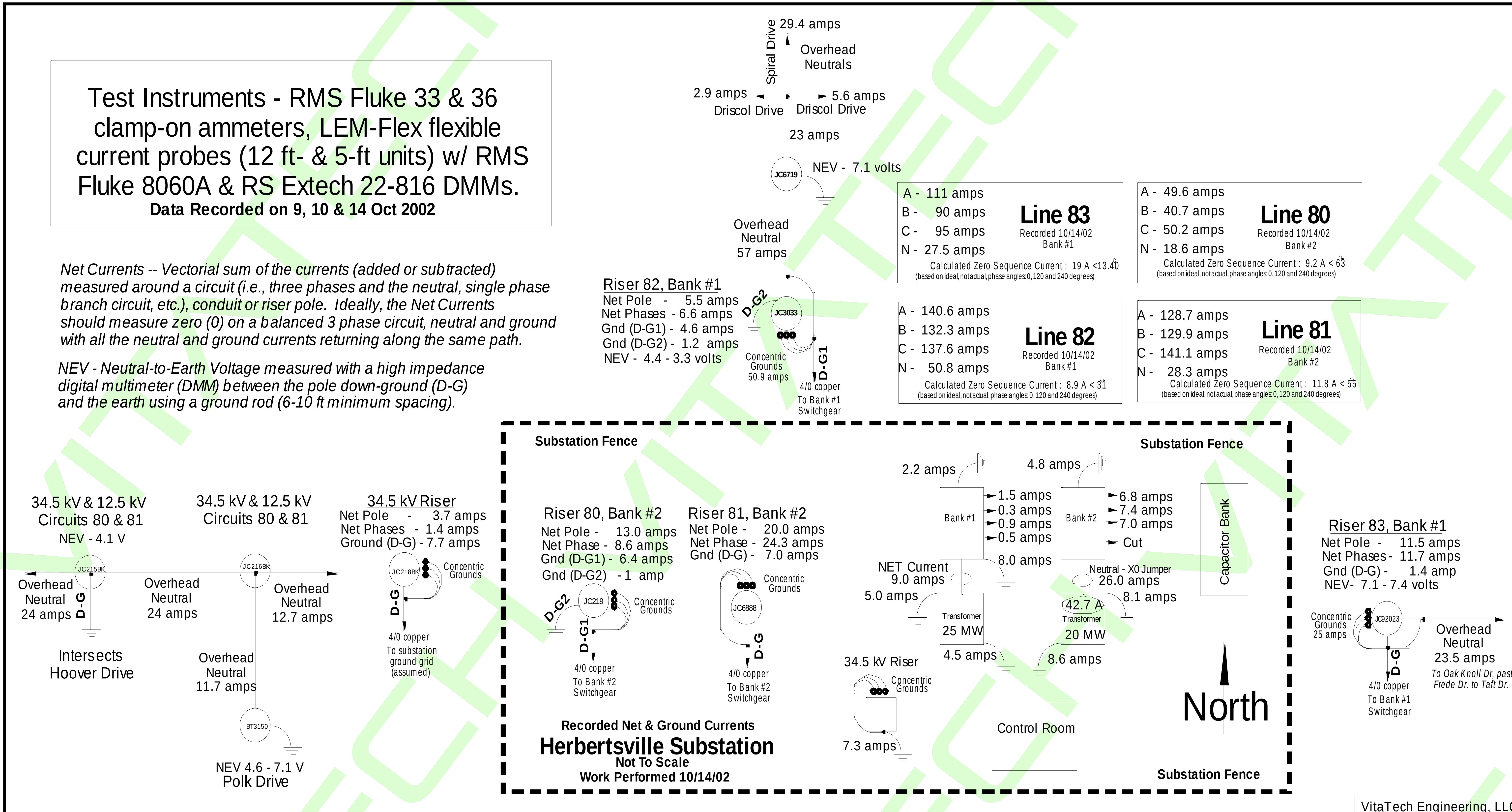


Figure #2, Herbertsville Substation & Vicinity Recorded Neutral, Ground & Net Currents

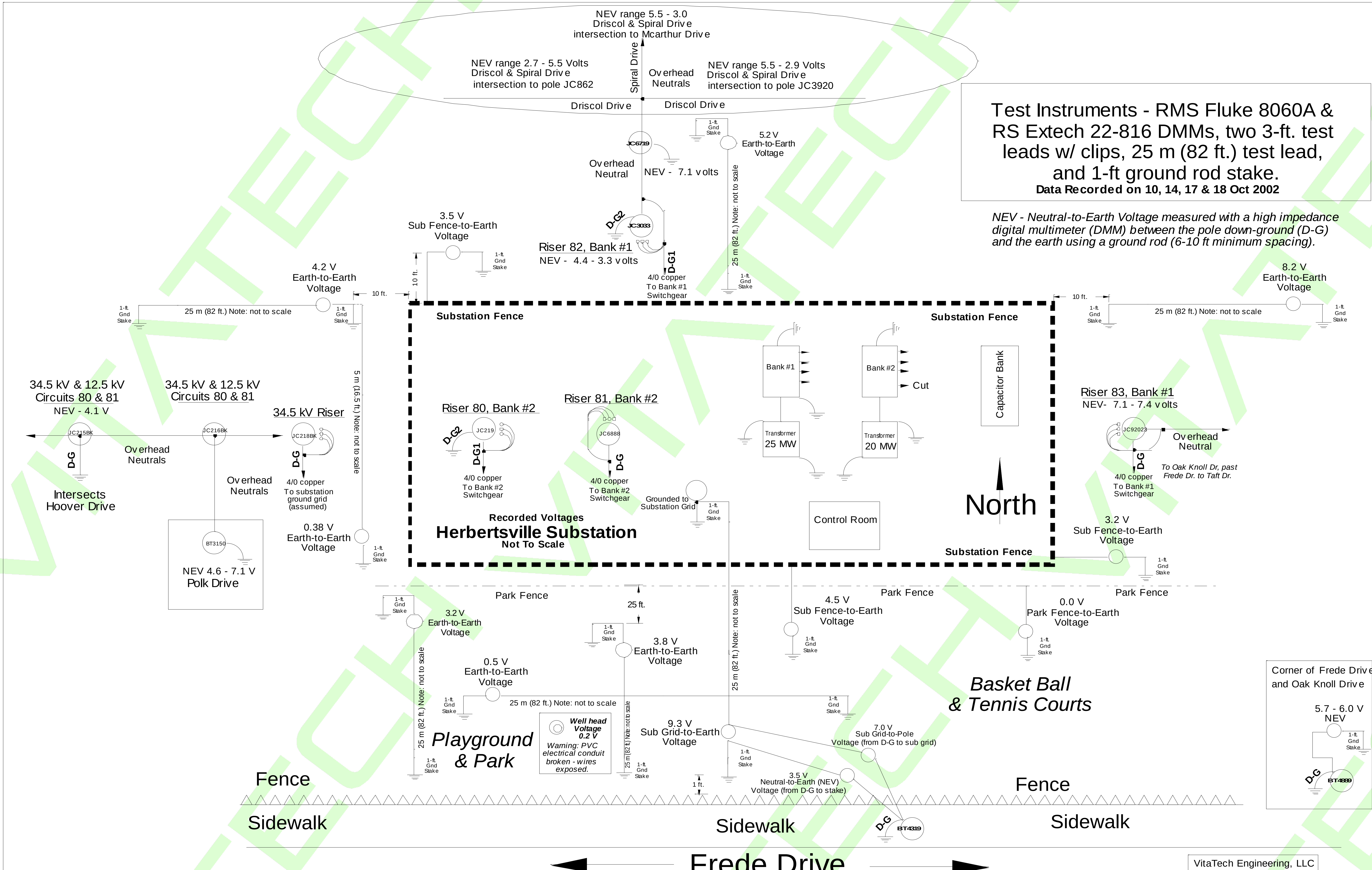
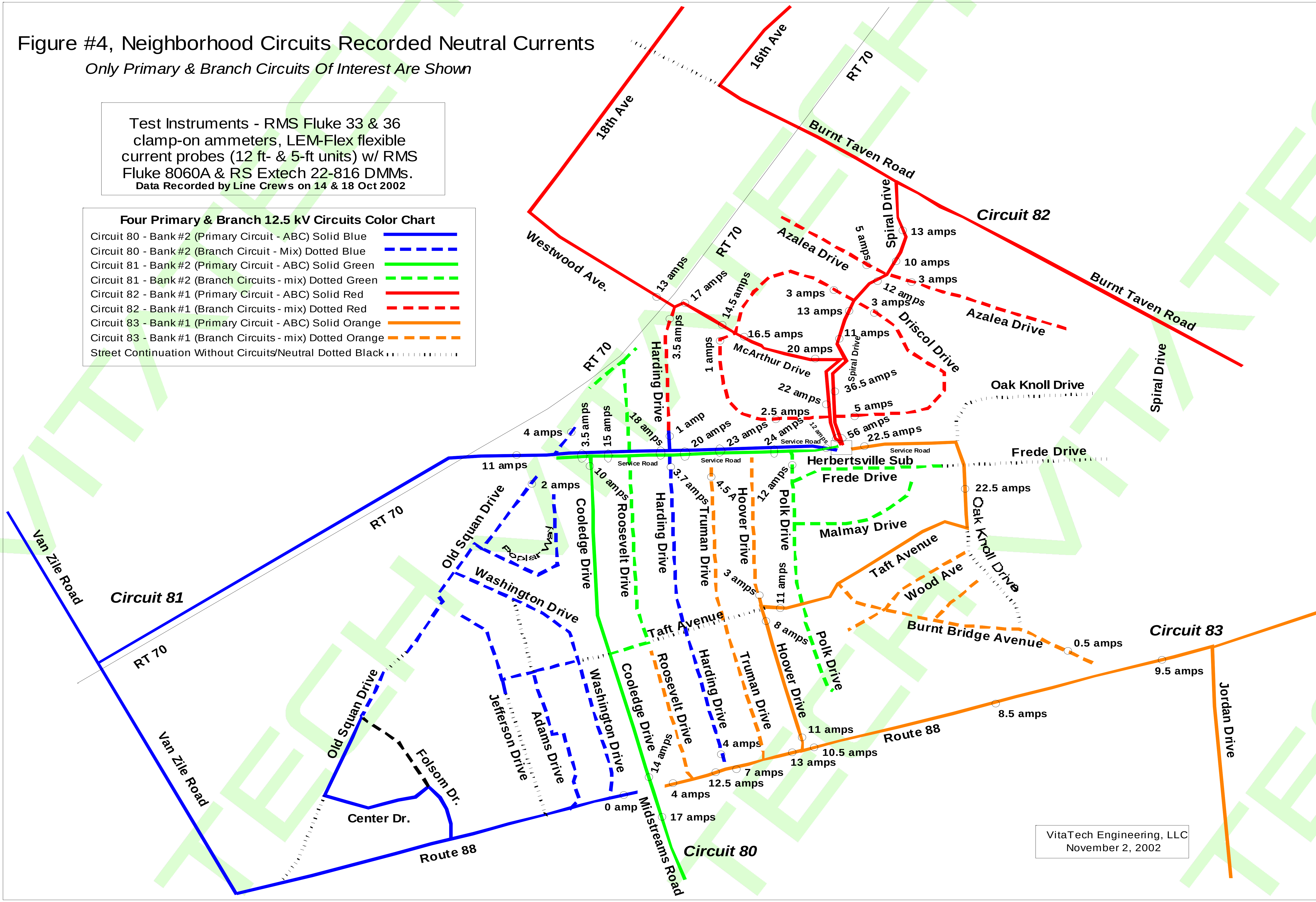
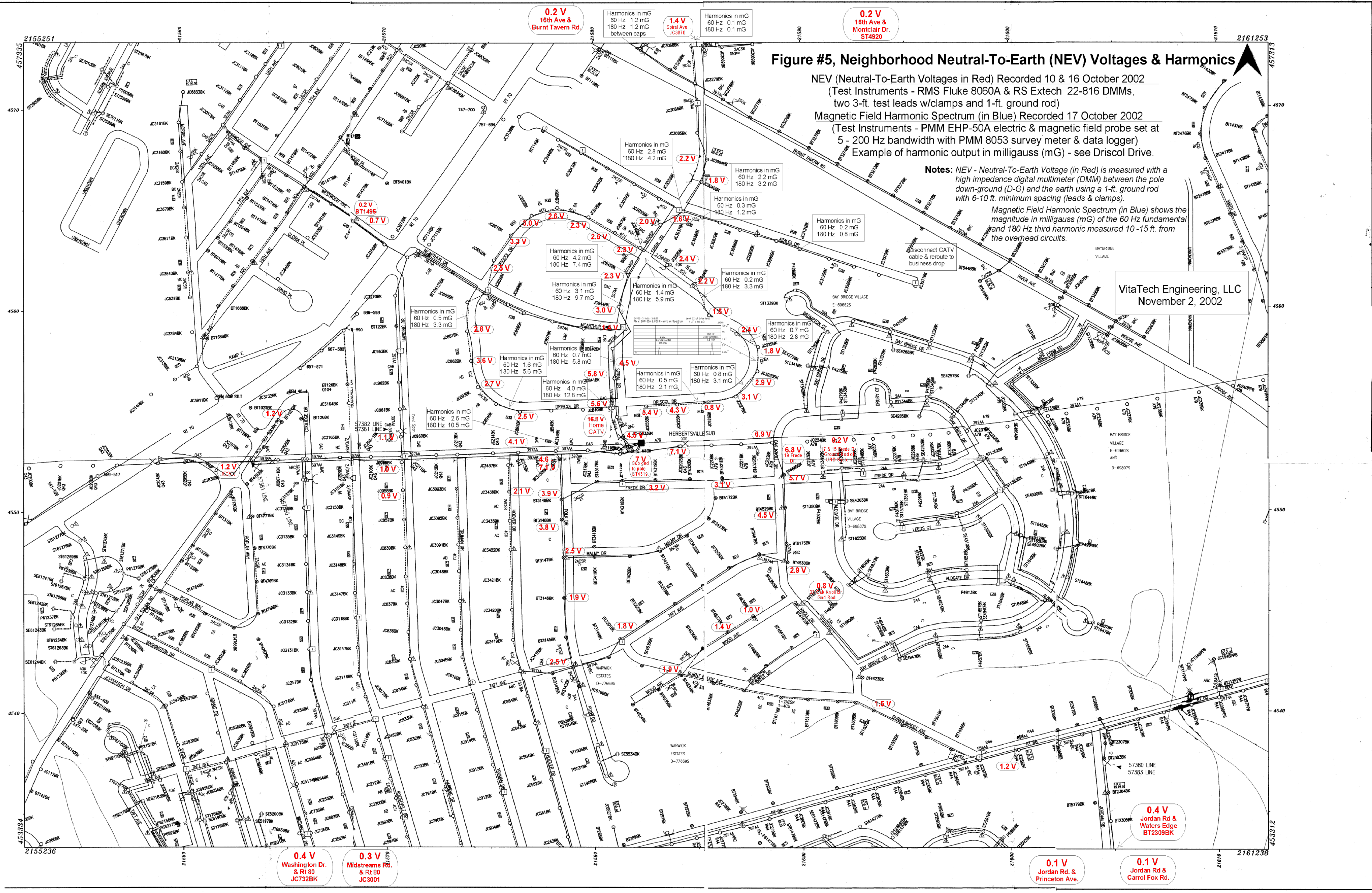


Figure #3, Herbertsville Substation & Vicinity Recorded Neutral & Earth Voltages

Figure #4, Neighborhood Circuits Recorded Neutral Currents

Only Primary & Branch Circuits Of Interest Are Shown





Prepared by: 2363

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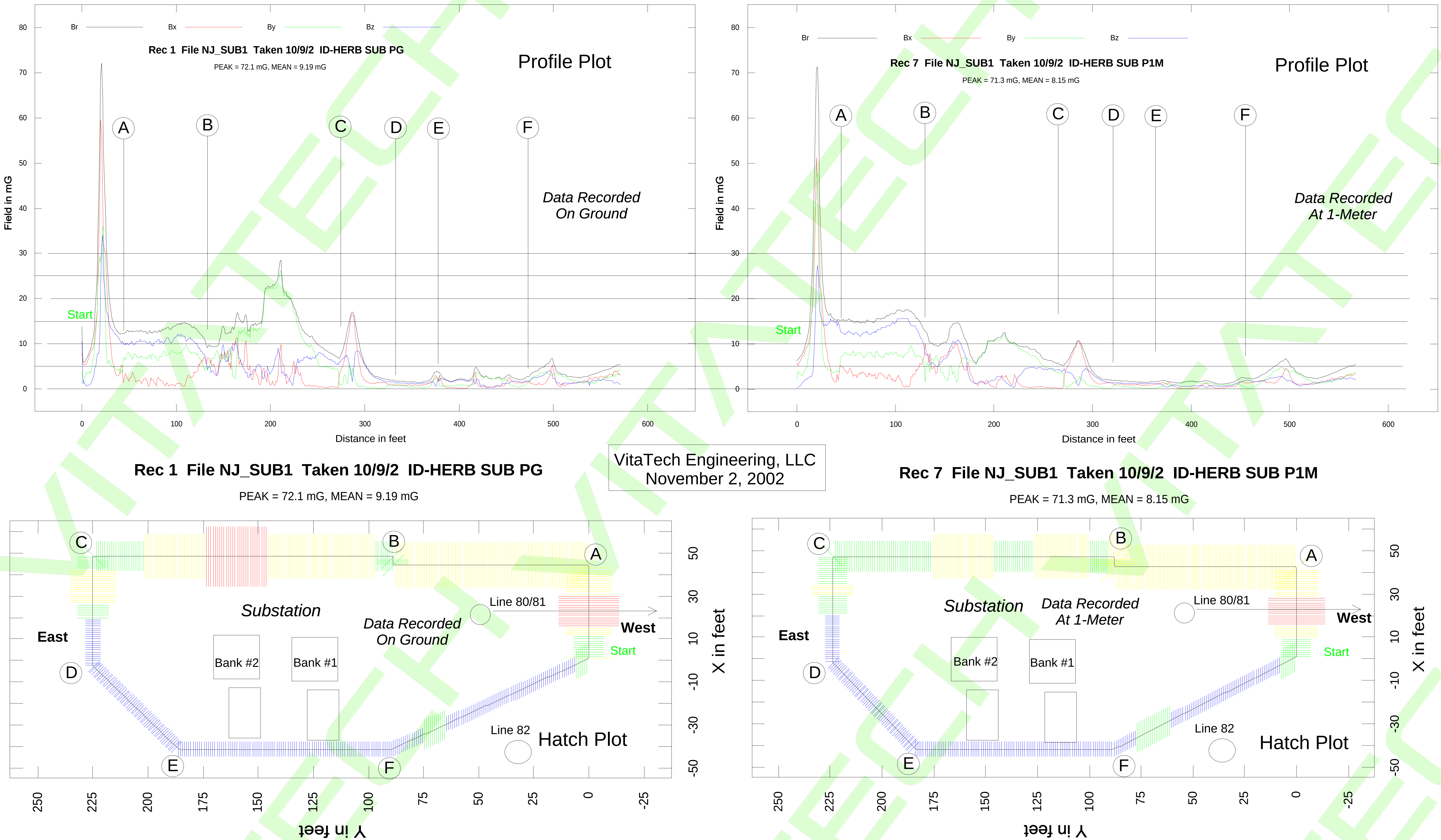
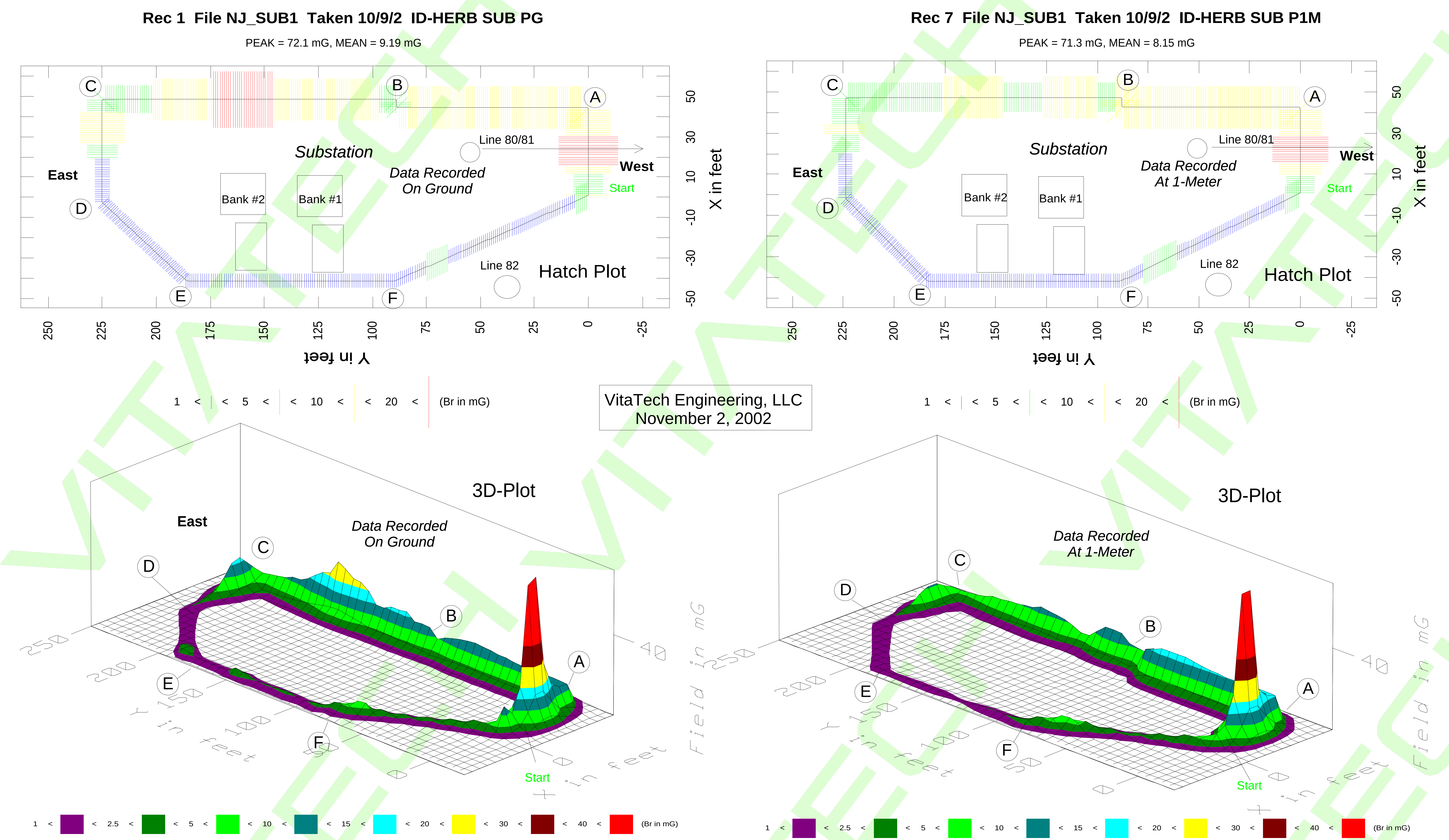


1 < 5 < 10 < 20 < (Br in mG)

Figure #6, Herbertsville Substation Magnetic Flux Density Data Perimeter Hatch & Profile Plots At Ground & 1-meter Levels

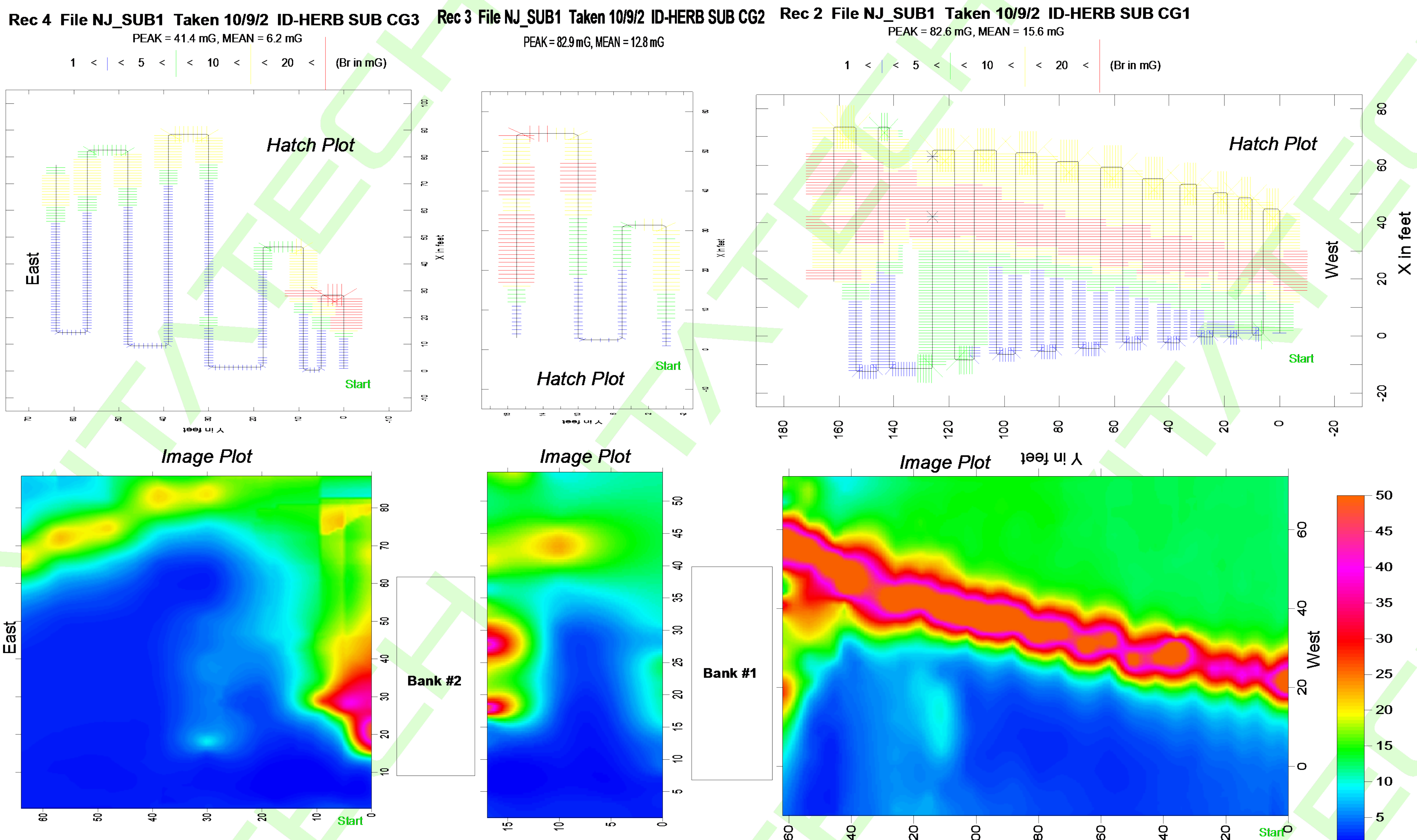
1 < 5 < 10 < 20 < (Br in mG)



Rec 1 File NJ_SUB1 Taken 10/9/2 ID-HERB SUB PG
PEAK = 72.1 mG, MEAN = 9.19 mG, STD = 8.51 mG, MEDIAN = 7.44 mG

Figure #7 Herbertsville Substation Magnetic Flux Density Data
Perimeter Hatch & Contour Plots At Ground & 1-meter Levels

Rec 7 File NJ_SUB1 Taken 10/9/2 ID-HERB SUB P1M
PEAK = 71.3 mG, MEAN = 8.15 mG, STD = 8.01 mG, MEDIAN = 6.28 mG



Data Recorded On Ground

Figure #8, Interior Herbertsville Substation Magnetic Flux Density Data Contour (Mapped) Hatch & Image Plots At Ground Level

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Figure #9 - Driscol Drive Magnetic Flux Density Data October 10, 2002
Hatch, Profile & 3-D Plots Recorded at Ground Level

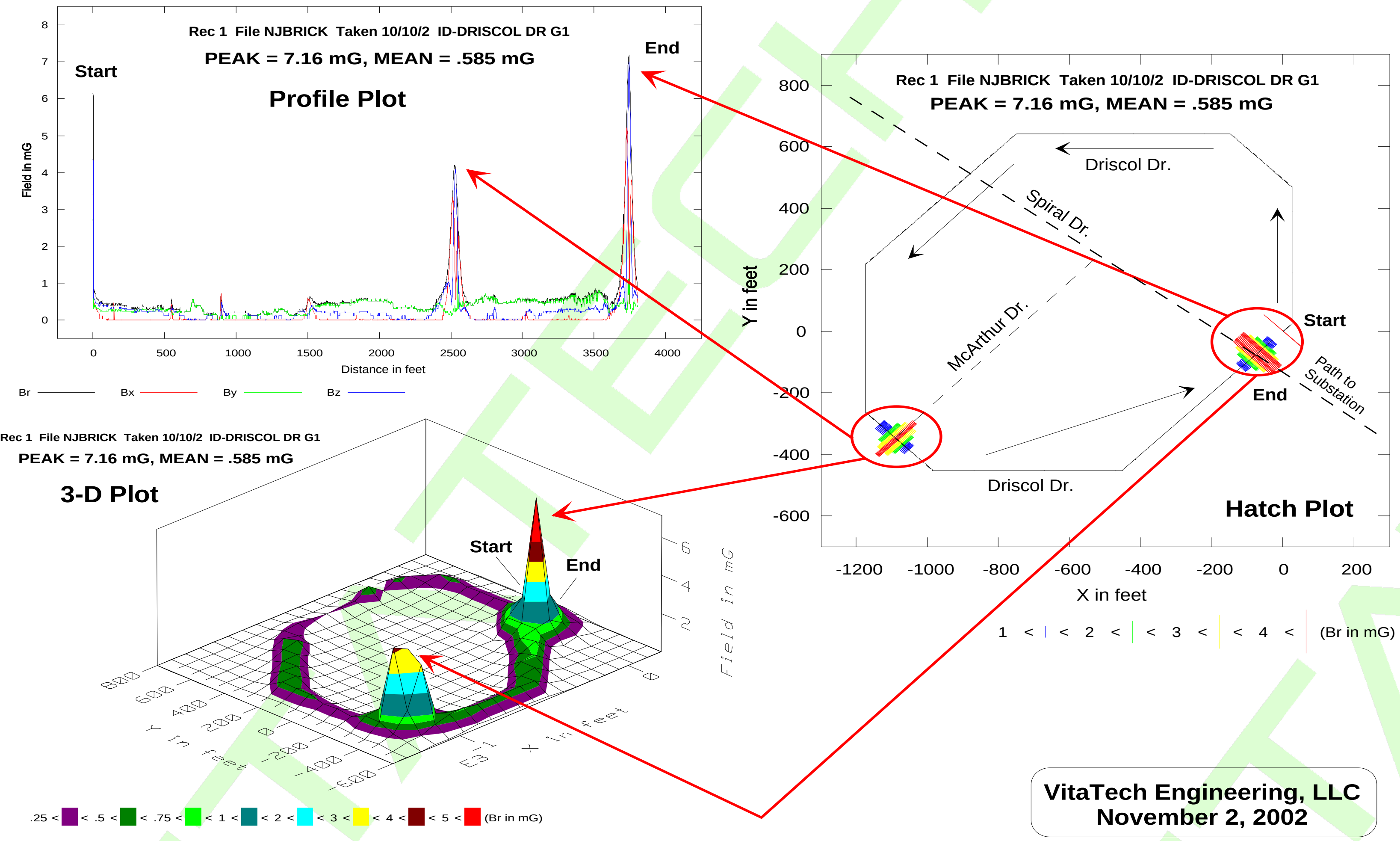


Figure #10- Spiral Drive Magnetic Flux Density Data, October 10, 2002
Hatch & Profile Plots Recorded at Ground Level

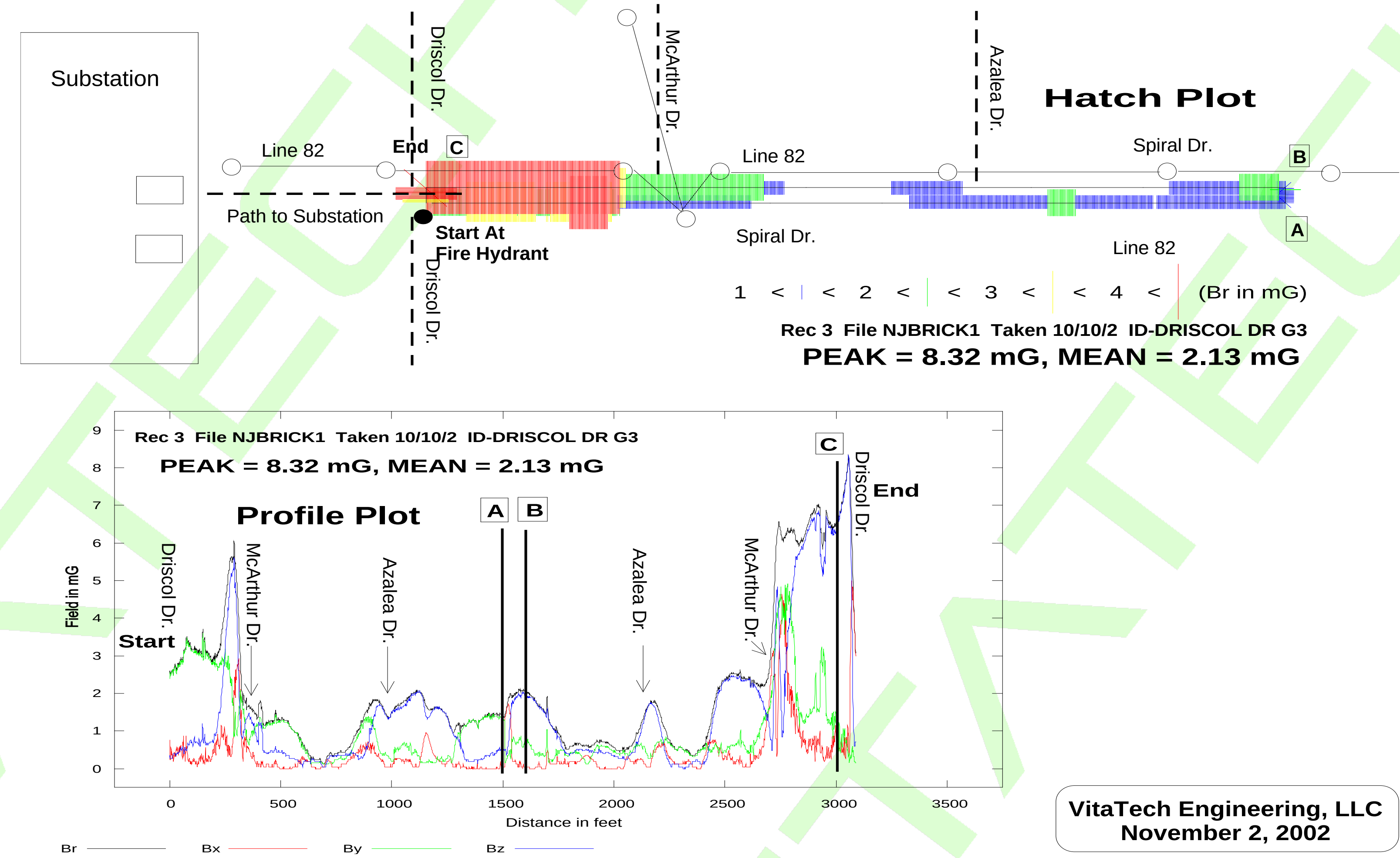


Figure #11 - Magnetic Flux Density Data Oak Knoll Dr. & Taft Ave., October 17, 2002
Hatch & Profile Plots Recorded at Ground Level

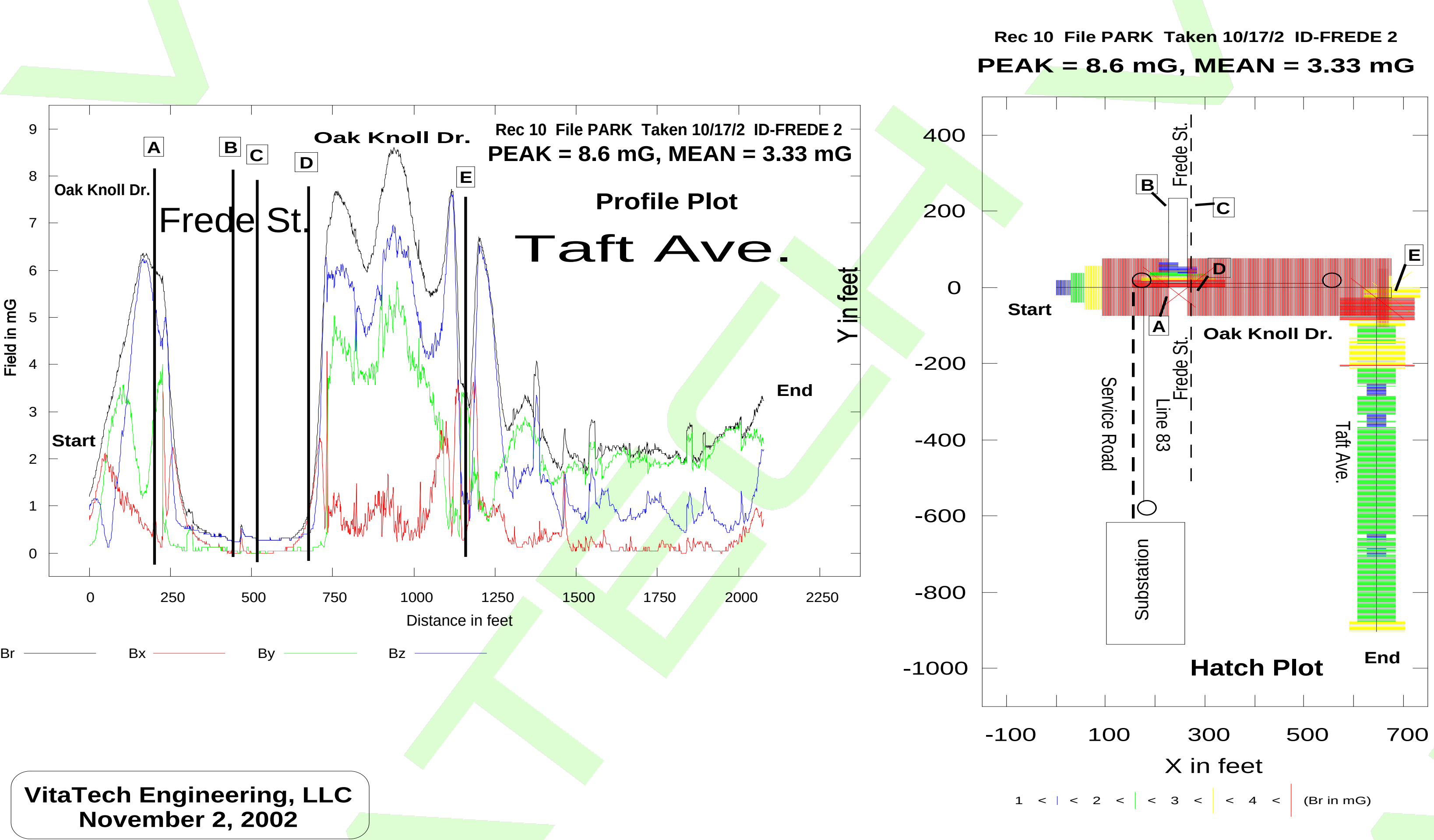


Figure #12 - Herbertsville Park Adjacent to Substation Magnetic Flux Density Data October 17, 2002
Park Perimeter Hatch, Profile, & 3-D Plots Recorded at Ground Level

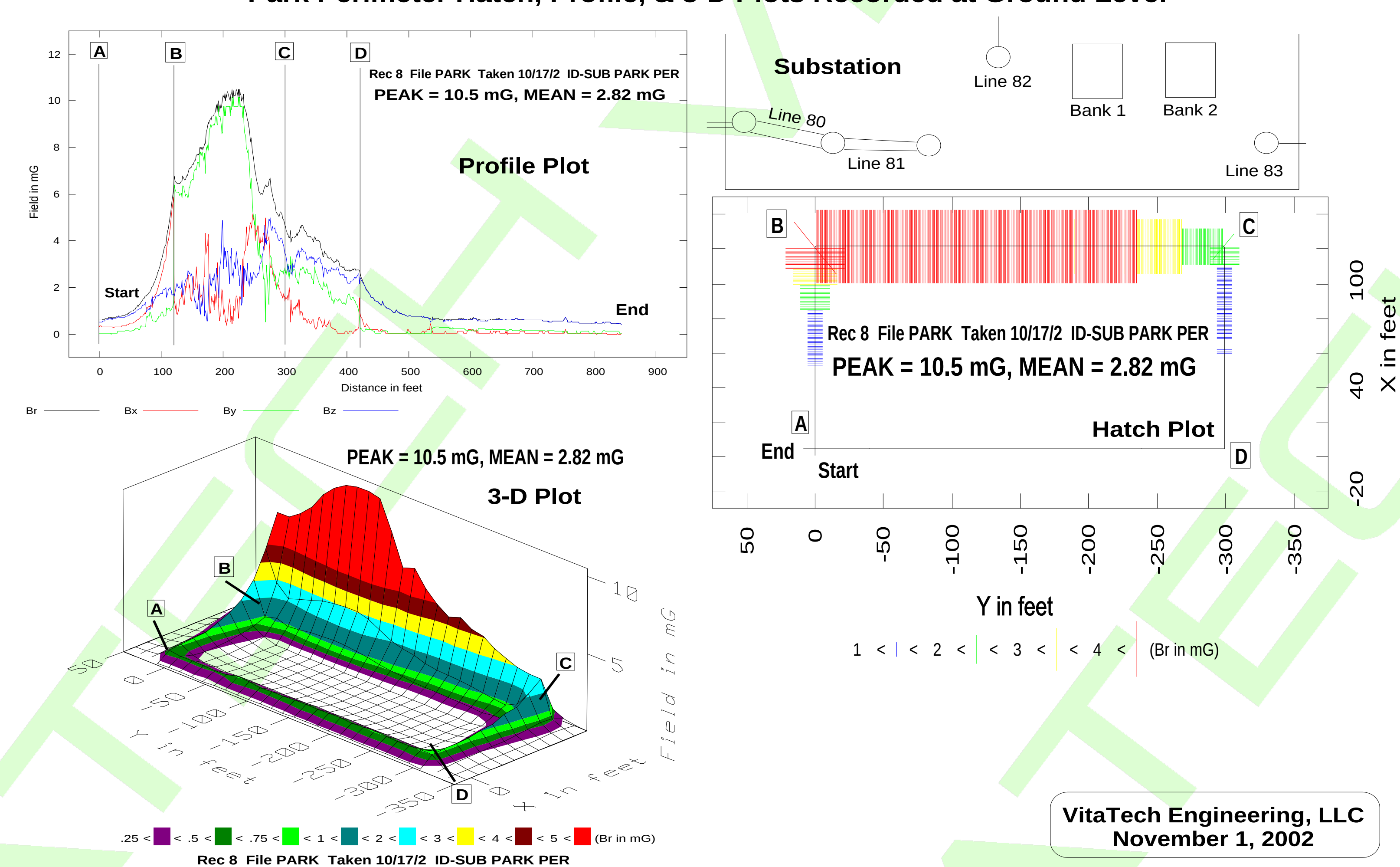


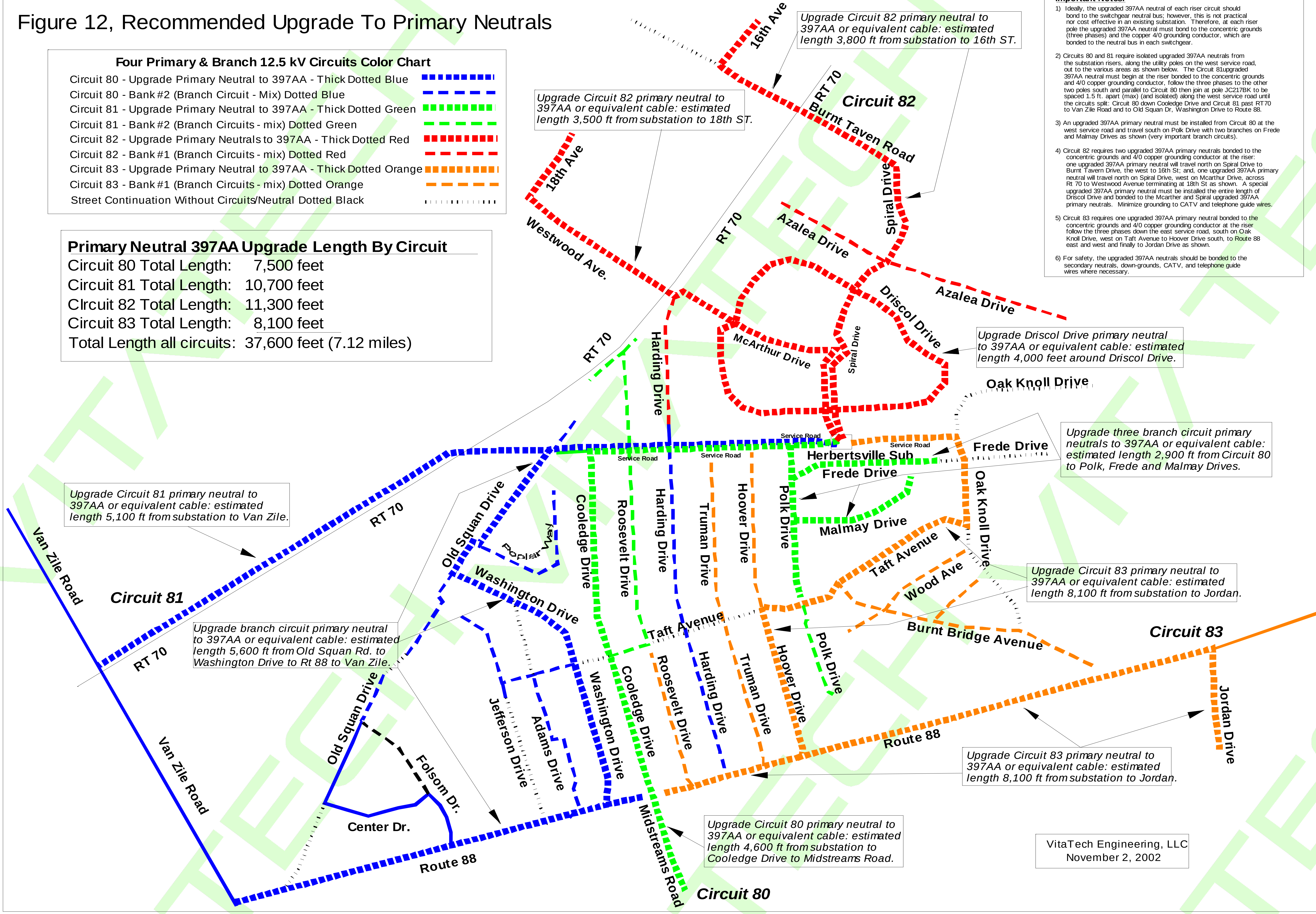
Figure 12, Recommended Upgrade To Primary Neutrals

Four Primary & Branch 12.5 kV Circuits Color Chart

- Circuit 80 - Upgrade Primary Neutral to 397AA - Thick Dotted Blue
- Circuit 80 - Bank #2 (Branch Circuit - Mix) Dotted Blue
- Circuit 81 - Upgrade Primary Neutral to 397AA - Thick Dotted Green
- Circuit 81 - Bank #2 (Branch Circuits - mix) Dotted Green
- Circuit 82 - Upgrade Primary Neutrals to 397AA - Thick Dotted Red
- Circuit 82 - Bank #1 (Branch Circuits - mix) Dotted Red
- Circuit 83 - Upgrade Primary Neutral to 397AA - Thick Dotted Orange
- Circuit 83 - Bank #1 (Branch Circuits - mix) Dotted Orange
- Street Continuation Without Circuits/Neutral Dotted Black

Primary Neutral 397AA Upgrade Length By Circuit

Circuit 80 Total Length:	7,500 feet
Circuit 81 Total Length:	10,700 feet
CIrcuit 82 Total Length:	11,300 feet
Circuit 83 Total Length:	8,100 feet
Total Length all circuits:	37,600 feet (7.12 miles)



Important Notes:

1) Ideally, the upgraded 397AA neutral of each riser circuit should bond to the switchgear neutral bus; however, this is not practical nor cost effective in an existing substation. Therefore, at each riser pole the upgraded 397AA neutral must bond to the concentric grounds (three phases) and the copper 4/0 grounding conductor, which are bonded to the neutral bus in each switchgear.

2) Circuits 80 and 81 require isolated upgraded 397AA neutrals from the substation risers, along the utility poles on the west service road, out to the various areas as shown below. The Circuit 81upgraded 397AA neutral must begin at the riser bonded to the concentric grounds and 4/0 copper grounding conductor, follow the three phases to the other two poles south and parallel to Circuit 80 then join at pole JC217BK to be spaced 1.5 ft. apart (max) (and isolated) along the west service road until the circuits split: Circuit 80 down Cooledge Drive and Circuit 81 past RT70 to Van Zile Road and to Old Squan Dr, Washington Drive to Route 88.

3) An upgraded 397AA primary neutral must be installed from Circuit 80 at the west service road and travel south on Polk Drive with two branches on Frede and Malmay Drives as shown (very important branch circuits).

4) Circuit 82 requires two upgraded 397AA primary neutrals bonded to the concentric grounds and 4/0 copper grounding conductor at the riser: one upgraded 397AA primary neutral will travel north on Spiral Drive to Burnt Tavern Drive, the west to 16th St; and, one upgraded 397AA primary neutral will travel north on Spiral Drive, west on Mcarthur Drive, across Rt 70 to Westwood Avenue terminating at 18th St as shown. A special upgraded 397AA primary neutral must be installed the entire length of Driscol Drive and bonded to the Mcarther and Spiral upgraded 397AA primary neutrals. Minimize grounding to CATV and telephone guide wires.

5) Circuit 83 requires one upgraded 397AA primary neutral bonded to the concentric grounds and 4/0 copper grounding conductor at the riser follow the three phases down the east service road, south on Oak Knoll Drive, west on Taft Avenue to Hoover Drive south, to Route 88 east and west and finally to Jordan Drive as shown.

6) For safety, the upgraded 397AA neutrals should be bonded to the secondary neutrals, down-grounds, CATV, and telephone guide wires where necessary.

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November 2, 2002

Vitatech's Final Assessment

- Primary neutrals on Lines 80, 81, 82 and 83 not sized to accommodate soil and exceptional Summer 2002 drought conditions.

- Poor soil conditions and low water table (saturation zone) at the Herbertsville substation and four distribution areas – impedes earth return currents traveling back to substation. Soil resistivity increased by a factor of 2-3 during the summer of 2002 drought: soil resistivity during normal summers with adequate rain probably ranged from 600 – 1200 ohm-meters, then increased to 2,000 to 3,000 ohm-meters, if not higher, during drought.

- Unbalanced phases exceeding 10% on Lines 80, 81, 82 and 83 during average load conditions -- could approach 20-25% during summer peak loads.

Vitatech's Recommendations

- Oversize primary neutrals on Lines 80, 81, 82 and 83 as specified in *Figure #12, Recommended Upgrade To Primary Neutrals* to match the size and impedance of the 397AA phase conductors. A total of 37,600 feet (7.12 miles) of upgraded 397AA primary neutrals are recommended to mitigate the stray voltage problem and achieve a neutral-to-earth voltage of 4-5 volts during summer months on the substation grid and down-grounds of the adjacent neighborhoods during peak summer loads. Specific routes and circuit length details for the recommended upgraded primary neutrals are provided in Figure #12; however, selected lateral circuits may also require upgraded 397AA neutrals to achieve the 4-5 volt summer performance objective including: Azalea Drive, Truman Drive, Harding Drive, Roosevelt Drive and Old Squan Drive.

- No additional ground rods, mats or plates are recommended for the substation ground grid; however, the substation ground plane should be expanded to the extents of the new fence line with additional grounds bonded from the grid to the fence, where needed. (Note: this will have no adverse effect on stray voltage.)

- Balance the phases on Lines 80, 81, 82 and 83 to within 10% (as measured by the SCADA equipment at the substation) during average loads (20-25%) and no more than 15% during peak summer loads to minimize zero-sequence currents.

Vitatech's Recommendations

- Returning earth currents are migrating up the down-grounds and raising the Neutral-to-Earth Voltage (NEV) and the Earth-to-Earth voltage in the neighborhood adjacent to the substation. Remember, the primary neutral return current is a sum of the harmonic (3rd,5th, 7th, 9th, 11th, 13th, 15th, etc.) components, especially the triplen harmonics, which are due to the zero-sequence currents of the unbalanced phases.

Therefore, decreasing the harmonic content on the primary neutrals (not an easy task) will concurrently reduce the neutral-to-earth voltage (NEV) on the down-grounds, substation grid and earth-to-earth voltages around the substation and adjacent neighborhood. EPRI verified Vitatech recommendations were correct and designed harmonic filters for the distribution lines which lowered the NEV to less than 3 V.