Sneak Circuit Analysis

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Acknowledgement:

Special gratitude is due to John Rankin for his pioneering work in sneak circuit analysis. That work has served as the basis for this brief training module.

Sources for sneak circuit examples used here are identified as references in the initial headers for each. Example 6, the most recent case, was suggested by Dr. Rodney Simmons and is based on information generously provided by J. Robert (Bob) Young, Vehicle Defect Investigator for the National Highway Traffic Safety Administration. Examples 2 and 3 are drawn from personal experience.

P. L. Clemens

Definition…

“**SNEAK CIRCUIT ANALYSIS** — Conducted on hardware and software to identify latent (sneak) circuits and conditions that inhibit desired functions or cause undesired functions to occur without a component having failed. The analysis employs recognition of topological patterns which are characteristic of all circuits and electrical/electronic systems.”

MIL-STD-882A, PARA. 5.5.1.2.C, June 1977

“… **A SNEAK CIRCUIT** is a designed-in signal or current path which causes an unwanted function to occur or which inhibits a wanted function. (This excludes) …component failures and electrostatic, electromagnetic, or leakage paths as causative factors. …(It also excludes) improper system performance due to marginal parametric factors or slightly out-of-tolerance conditions.”

John P. Rankin, 1973 (Ref. 1)

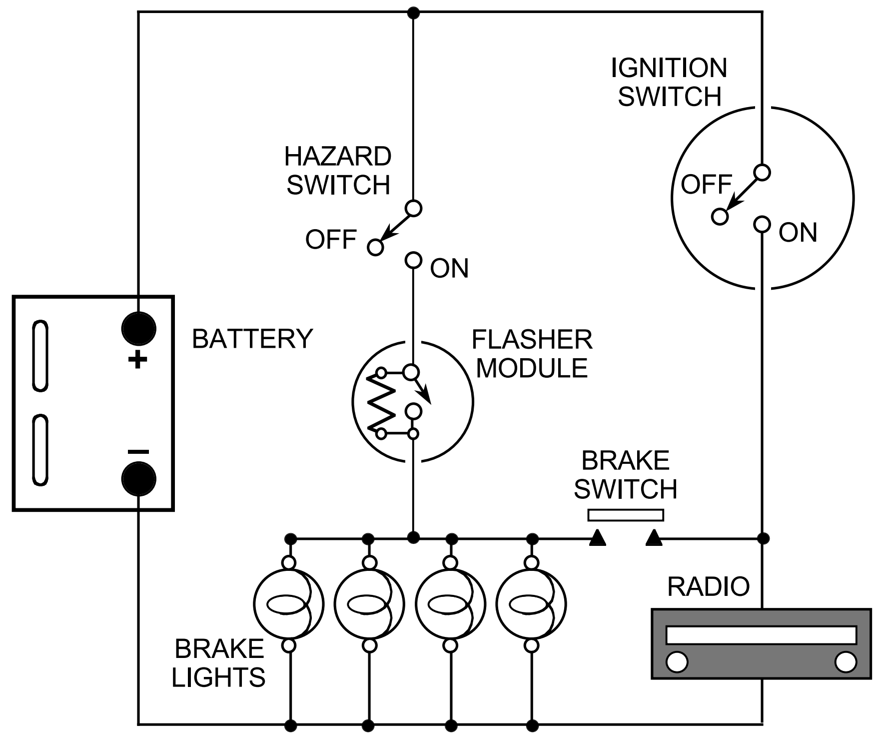
“…**SNEAK CIRCUITS** are conditions which are present but not always active, and they do not depend on component failure.”

E. J. Hill and L. J. Bose, 1975 (Ref. 2)

Example
Sneak Circuits

1. Auto Brakes, Flasher and Radio
(Some autos — late ’60s Refs. 3, 4, & 5)…

- **REQUIREMENTS:** Radio cannot be left ON with ignition switch OFF. Hazard flasher must be operable with ignition switch OFF.
- **DESIGN:** Radio is in series with ignition switch. Hazard switch and flasher bypass ignition switch.
- **SCENARIO:** Radio operates synchronously with brake lights when ignition switch is used to turn off radio, hazard flasher is operated, and brake pedal is depressed.



FIND THE SNEAK!

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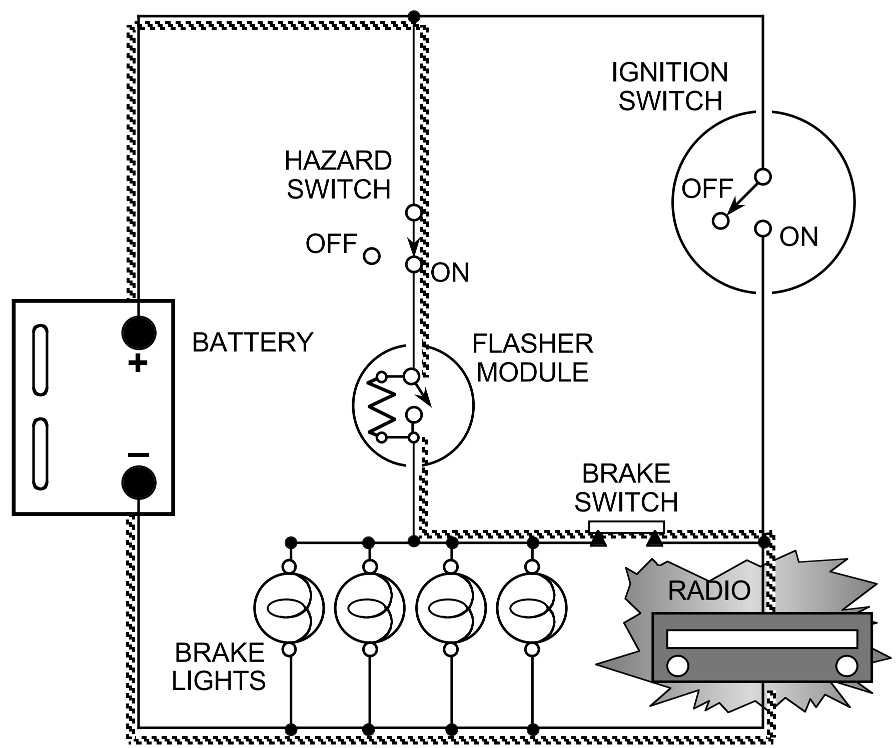
1. Auto Brakes, Flasher and Radio
Sneak Disclosed…

SNEAK: Brake switch provides reverse-current path, placing radio in parallel with brake lights.

- **Is this a *true* Sneak Circuit?**
  - **Will it cause *harm?***
    - **How might it be *corrected?***



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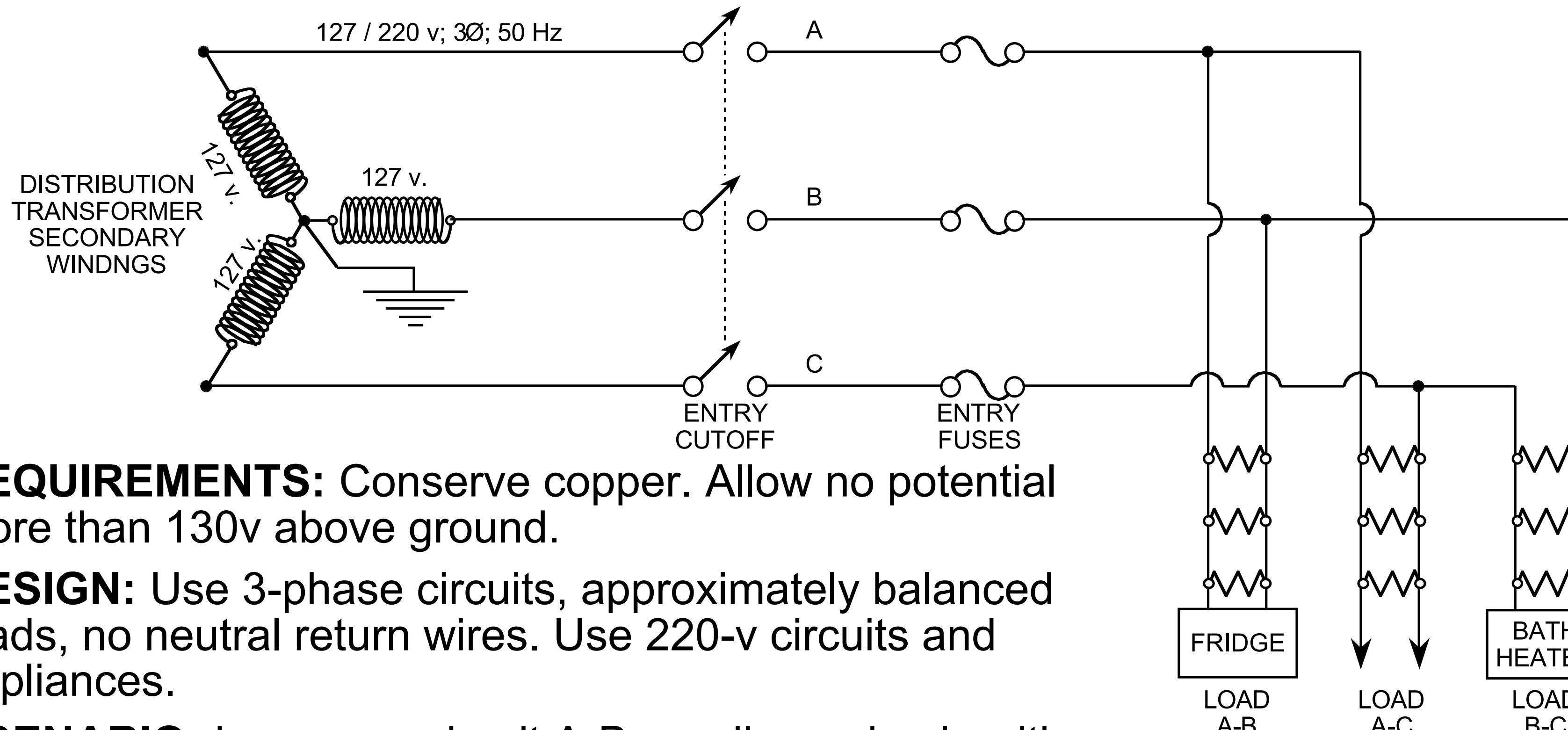
2. Western European Household Wiring (153 Ave. de Broqueville, Brussels)…

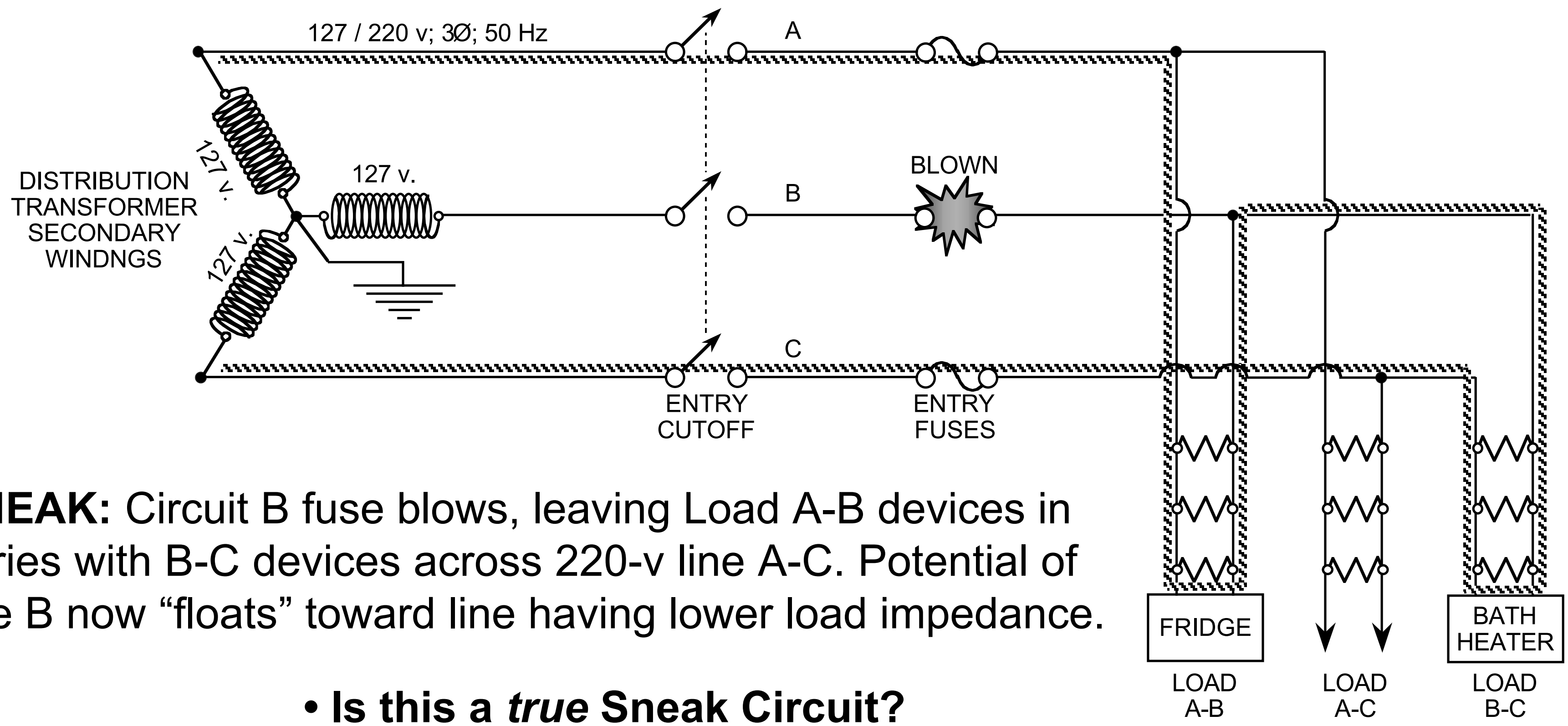


- **REQUIREMENTS:** Conserve copper. Allow no potential more than 130v above ground.
- **DESIGN:** Use 3-phase circuits, approximately balanced loads, no neutral return wires. Use 220-v circuits and appliances.
- **SCENARIO:** Lamps on circuit A-B are dim and only with circuit B-C lamps or bathroom heater on. Fridge operates erratically and only with bathroom heater on. All circuit A-C devices function normally.

FIND THE SNEAK!

2. Western European Household Wiring

Sneak Disclosed…



SNEAK: Circuit B fuse blows, leaving Load A-B devices in series with B-C devices across 220-v line A-C. Potential of line B now “floats” toward line having lower load impedance.

- **Is this a *true* Sneak Circuit?**
  - **Will it cause *harm?***
    - **How might it be *corrected?***

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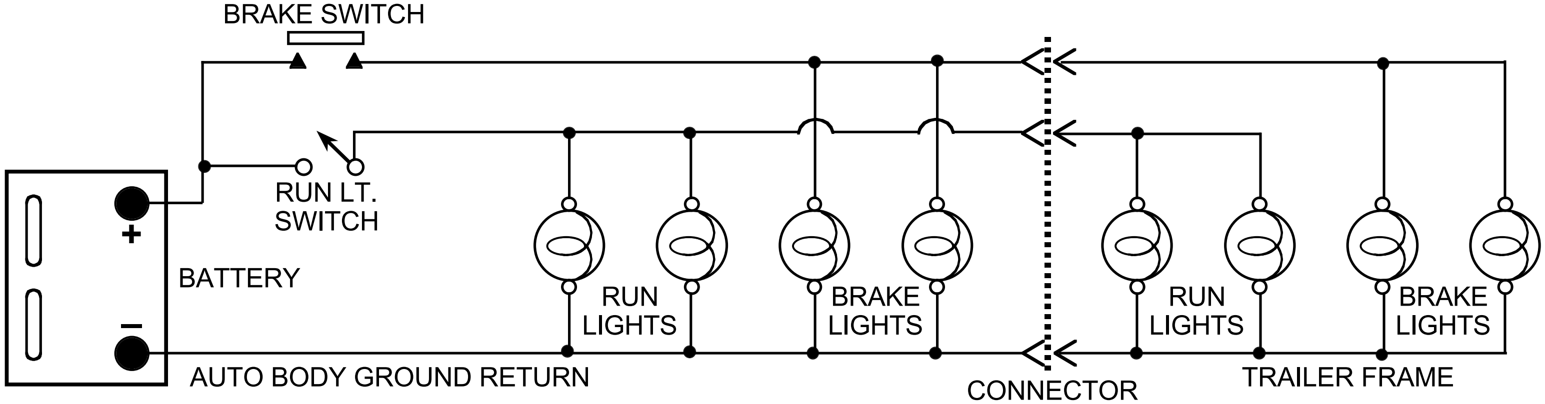
3. Auto and Trailer Light System
(Current Standard Practice)...



- **REQUIREMENTS:** Trailer lights duplicate functions of auto lights. Trailer lights are readily disconnected from auto.
- **DESIGN:** Connector places trailer brake and running lights in parallel with auto lights.
- **SCENARIO:** With running light switch closed, running lights on auto and trailer both function until brake is operated. Then auto brake lights operate and all trailer lights are dark. With running light switch open, operating brake produces dim glow of all running lights, proper operation of auto brake lights, but no operation of trailer brake lights.

FIND THE SNEAK!

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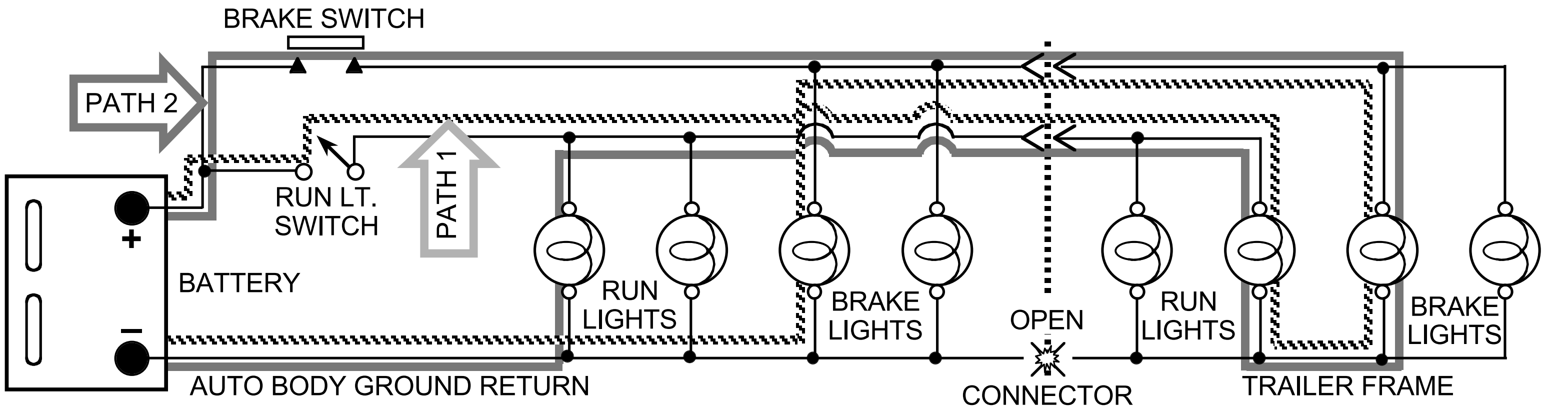
3. Auto and Trailer Light System
Sneak Disclosed…



SNEAK: Ground return circuit from trailer frame to auto is "open" (or high resistance). Path 1 sees running light switch closed; high resistance trailer running lights are in series path to ground through low resistance trailer and auto brake lights. Thus, they glow. Operating auto brake lights eliminates this path, extinguishing trailer lights. Path 2 sees running light switch "open." Operating brake places both running light pairs in series with trailer brake lights, and they glow at reduced voltage.

- **Is this a *true* Sneak Circuit?**
  - **Will it cause *harm?***
    - **How might it be *corrected?***

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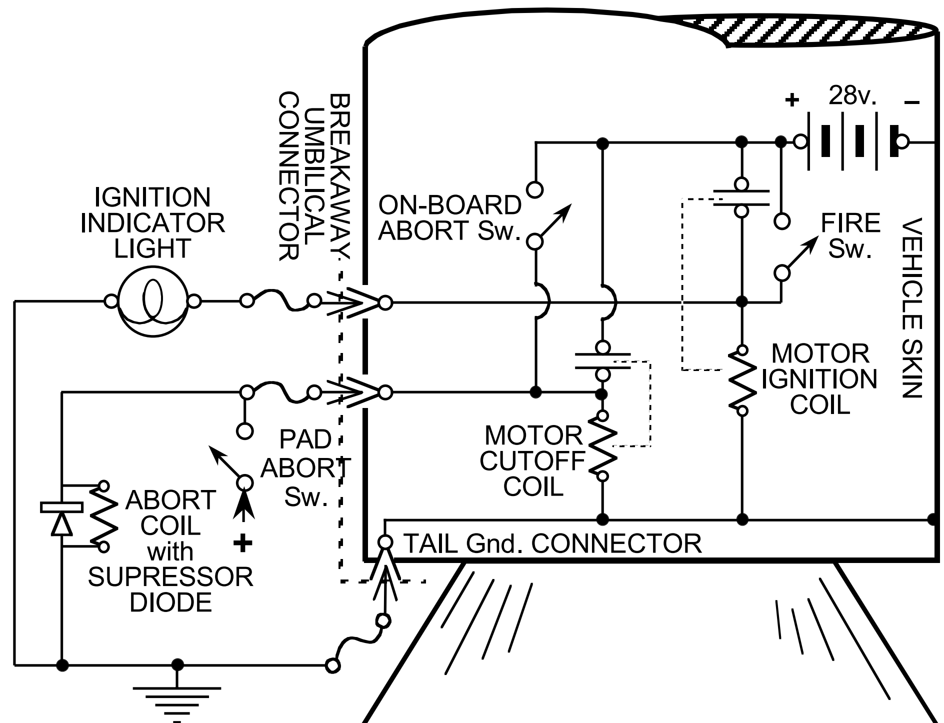
4. Redstone/Mercury Booster Firing Circuit (1961 config. Ref. 1)…

- **REQUIREMENTS:** On-board fire control signal ignites motor. Abort prior to liftoff is by Pad Abort Sw. On-board abort is also enabled full time.

- **DESIGN:** Motor is ignited by on-board Fire Sw., annunciated through umbilicus. Ignition coil self latches to on-board power supply. On-board Motor Cutoff Coil is energized by On-Board Abort Sw. Cutoff Coil self latches to on-board power supply. Umbilicus and Tail Gnd. Connector are separate liftoff breakaways.



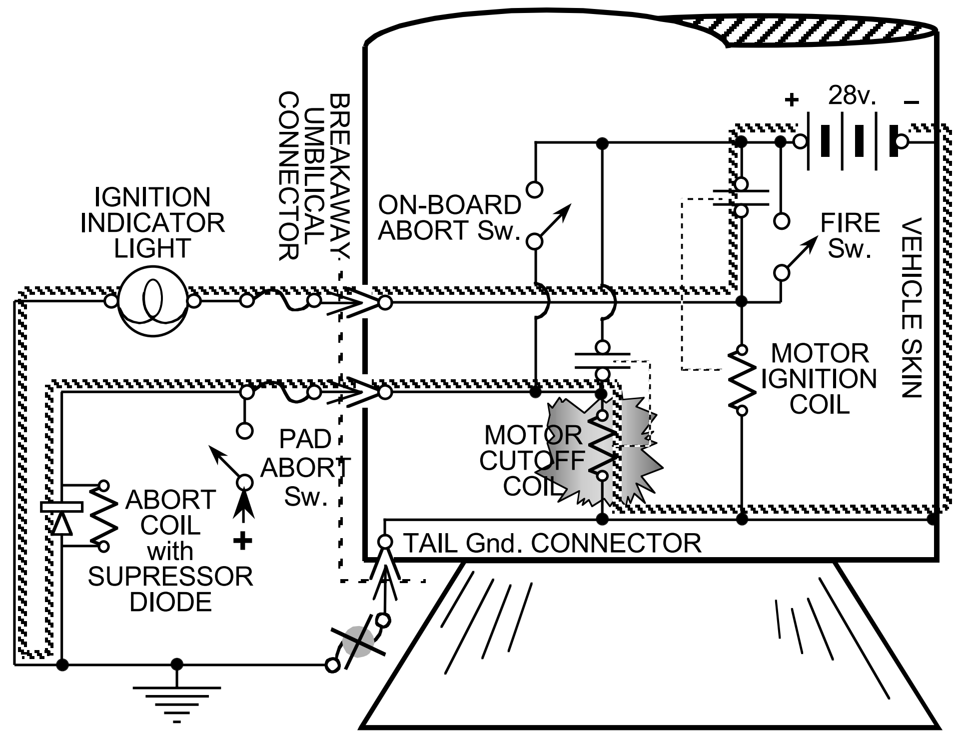
- **SCENARIO:** On 21 Nov. 1961, Redstone motor fired and began liftoff. After "flight" of a few inches, motor cut off and vehicle settled on pad. Mercury capsule jettisoned and impacted 1,200 ft. away. Area was cleared for 28 hours. for Redstone batteries to drain down and liquid oxygen to evaporate. Damage was slight. Booster and Mercury capsule were later reused.

FIND THE SNEAK!

4. Redstone/Mercury Booster Firing Circuit
Sneak Disclosed…

SNEAK: Tail Gnd. Connector broke away 29 msec prior to umbilicus separation, leaving current path as shown for excitation of Motor Cutoff Coil through Ignition Indicator Light and Suppressor Diode.

Result: Abort at liftoff.



- Is this a *true* Sneak Circuit?
  - Will it cause *harm?*
    - How might it be *corrected?*

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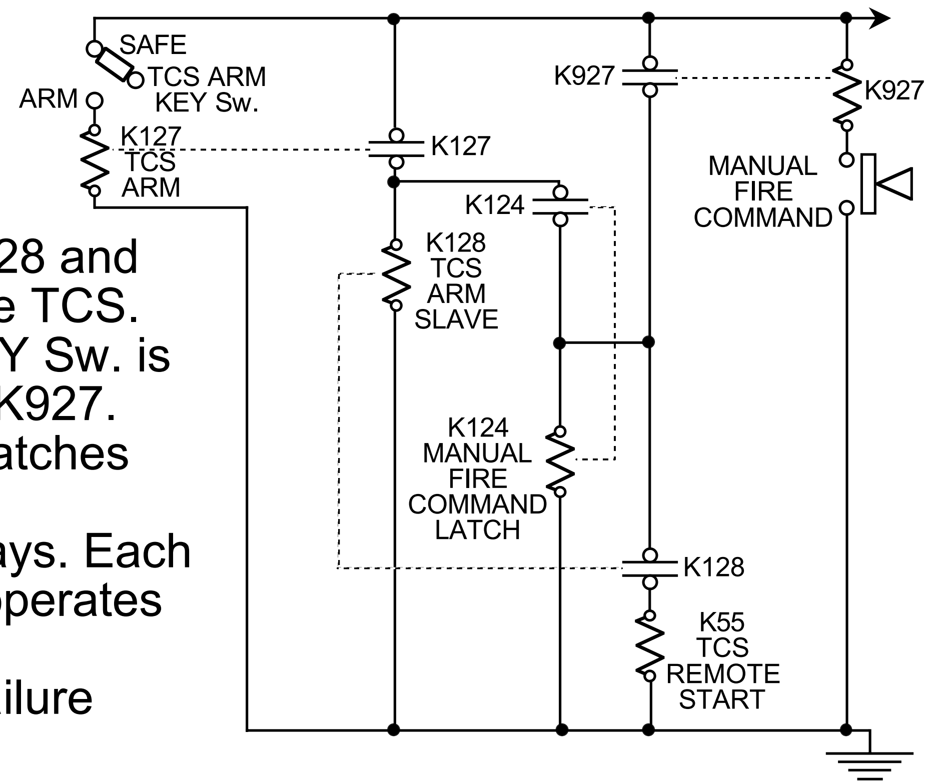
5. Apollo-Saturn 1st-Stage Firing Circuit (Simplified 1973 config. — Ref. 3)…

- **REQUIREMENTS:** Independent "ARM" and "FIRE COMMAND" operations are both necessary to initiate Terminal Countdown Sequence (TCS).
- **DESIGN:** K55 is energized only if both K128 and K927 are closed. K55 starts uninterruptible TCS. K127 energizes K128 when TCS ARM KEY Sw. is closed. Manual Fire Command energizes K927. (K128 is K127 arm slave repeater; K124 latches manual fire command, but only if K127 is energized.) NOTE: There are only five relays. Each has only one pair of N.O. contacts. Each operates only once. Detection of design errors and troubleshooting are simplified. Available failure modes are minimized.



- **SCENARIO:** Analysis discloses a sneak path in all 1st-stage Saturn rocket firing circuits. The sneak circuit bypasses the key-operated Safe-Arm safety switch; 7.5M lb of thrust can be unleashed inadvertently.

FIND THE SNEAK!

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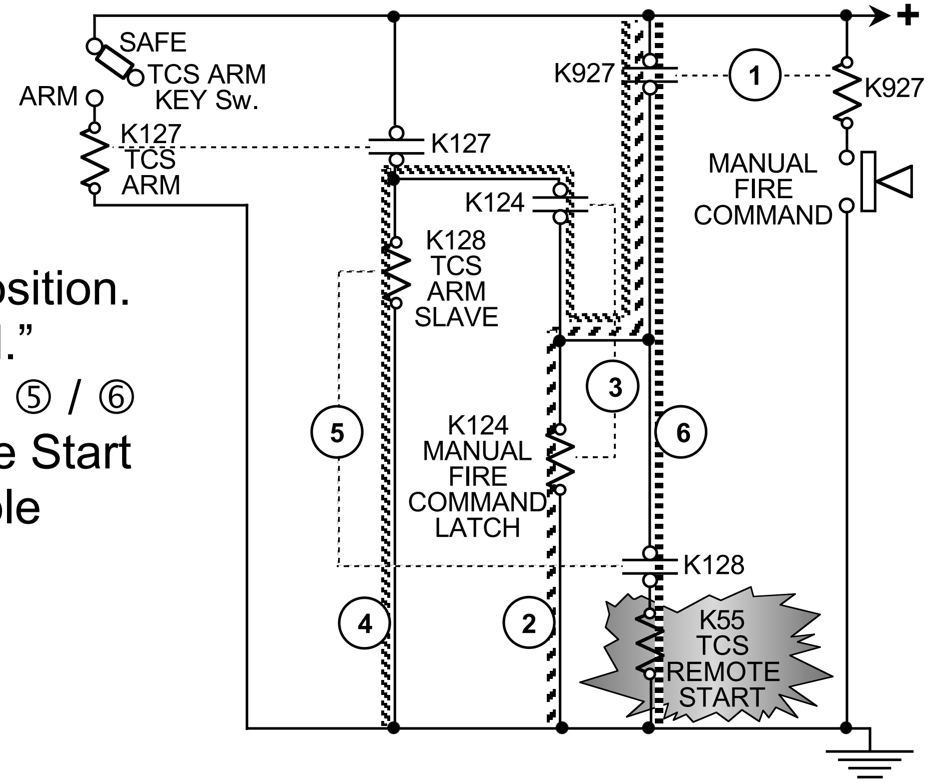
5. Apollo-Saturn 1st-Stage Firing Circuit Sneak Disclosed…

SNEAK: TCS Arm Key Sw. is in SAFE position. Manual Fire Command button is "bumped." Event/current-path train is ① / ② / ③ / ④ / ⑤ / ⑥ …hence, uninterruptible K55 TCS Remote Start is energized without arming! Uninterruptible Terminal Countdown Sequence begins.



- **Is this a *true* Sneak Circuit?**
  - **Will it cause *harm?***
    - **How might it be *corrected?***

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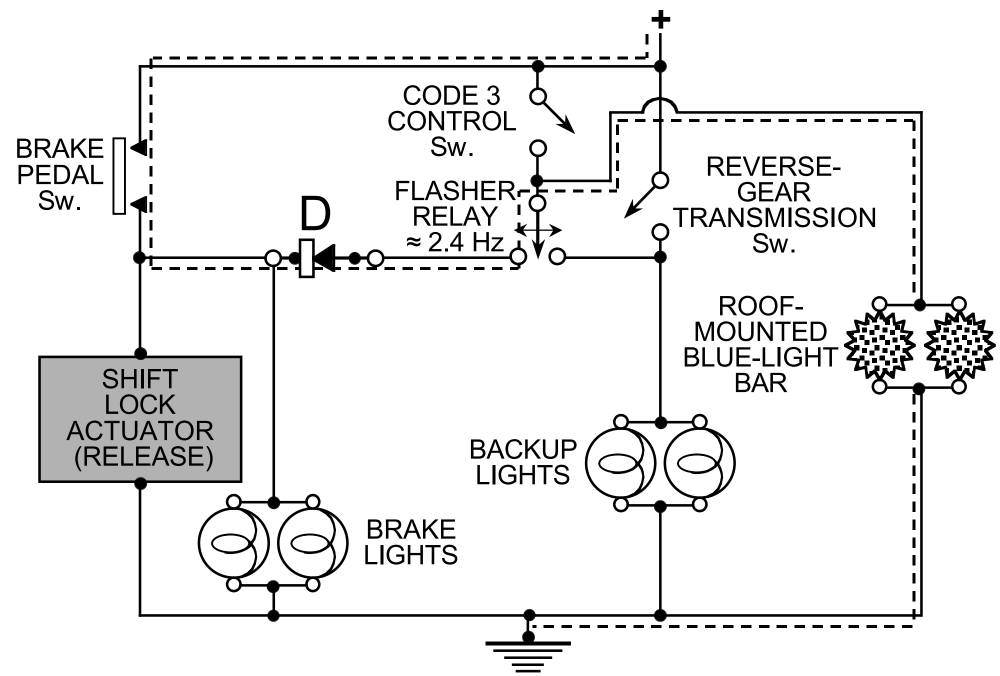
6. Runaway Police Van
(Simplified — Ref. 9)…

- **REQUIREMENTS:** Code 3 Control Sw. activates roof-mounted Blue-Light Bar and causes Brake and Backup Lights to pulse alternately at ≈ 2.4 Hz.
- **DESIGN:** After-purchase modification uses alternating Flasher Relay to accomplish requirements. Diode (D) prevents Brake Pedal Sw. from activating Blue-Light Bar via current path ---------- . Blue-Light Bar, Diode, Flasher Relay, and Code-3 Control Sw. are all after-purchase additions.

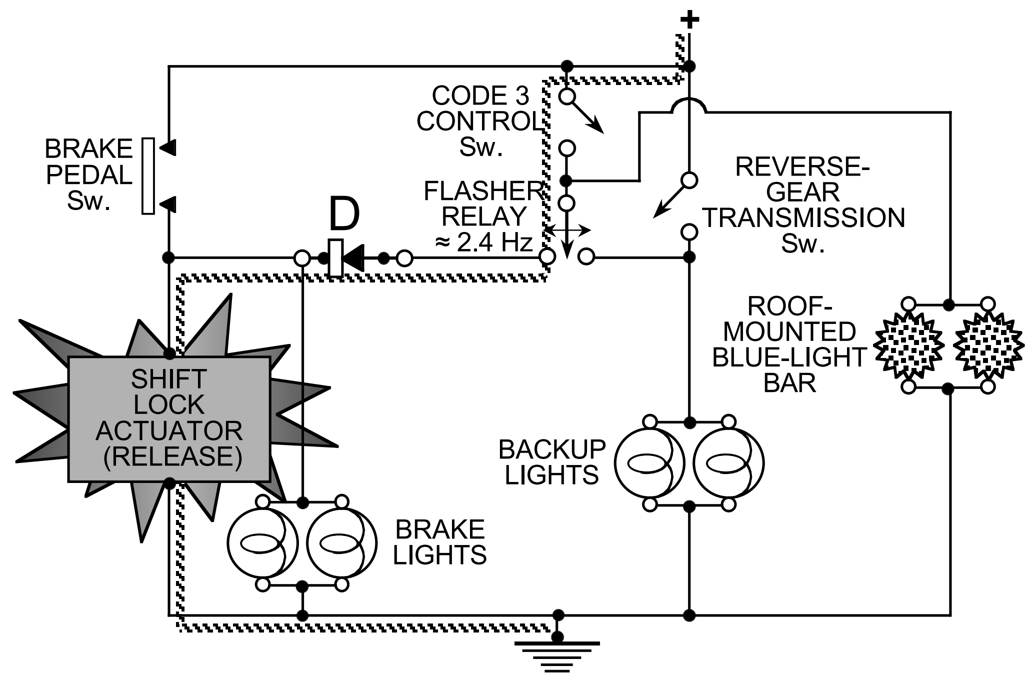


- **SCENARIO:** On 4 Dec. 1998, an apparent police van shift lock failure combined with suspected misapplication of accelerator rather than brake resulted in sudden acceleration, the death of two pedestrians, and injury of nine.

FIND THE SNEAK!

6. Runaway Police Van
Sneak Disclosed…

SNEAK: Closing Code 3 Control Sw. provides pulsing path through Flasher Relay and Diode to disengage Shift Lock, allowing vehicle operator to shift into gear while applying accelerator rather than brake.



- **Is this a *true* Sneak Circuit?**
  - **Will it cause *harm?***
    - **How might it be *corrected?***

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Sneak Circuit Types (Refs. 1,2, & 6)…

- **SNEAK PATH —** causes current to flow along an unexpected route. Examples 1 (p 5) and 5 (p 13).
- **SNEAK TIMING —** causes or prevents flow of current to activate or inhibit a function at an unexpected time. Example 4 (p 11).
- **SNEAK INDICATION —** causes ambiguous or false display of system operating conditions …e.g., Electromatic Relief Valve, Three Mile Island Reactor No. 2, valve solenoid excitation was interpreted as valve position (Ref. 7).
- **SNEAK LABEL —** causes incorrect stimuli to be initiated through operator error …e.g., Morgantown Rapid Transit System, ganged switch labeled “Battery Disconnect” both disconnected battery from bus and de-energized critical systems (Ref. 2).

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Sneak Path Analysis Methods…

- **SYSTEMATIC INSPECTION —** Examine circuit branch by branch, applying intuitive appreciation of intended function, seeking means for malfunction.
- **FAULT TREE ANALYSIS —** Postulate outcome of unknown circuit fault(s) as tree TOP event. Explore paths to TOP using rules of symbolic logic.
- **BOOLEAN ALGEBRA —** Express complete circuit logic in Boolean equations. Reduce the equations and compare with reduced Boolean expressions for desired functional algorithm (Ref. 8).
- **TOPOGRAPHIC ANALYSIS —** (Refs. 1, 2, 4, and 6).

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Basic Node Topographs

Topograph Approach (Refs. 1, 2, 4, & 6) …

- Ensure that drawings for analysis accurately portray complete as-built circuit.
- Ignore distributed parameters.
- Consider fuses, circuit breakers, and connectors as switches.
- Convert circuit to equivalent topographic network trees. (Redraw repeatedly, as necessary.)
- Inspect topographic trees for…
  - adequacy to perform as intended.
  - freedom from unintended paths.

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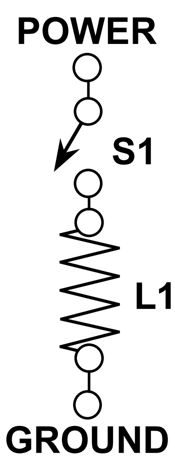
Single Line Topograph…



SNEAK POSSIBILITIES/CLUES:

1) **Switch S1 open when Load L1 function desired.**
2) **Switch S1 closed when Load L1 function not desired.**
3) **Label of Switch S1 does not reflect function of L1.**
4) **Switch S1 closed when Load L1 = 0.**

…etc.

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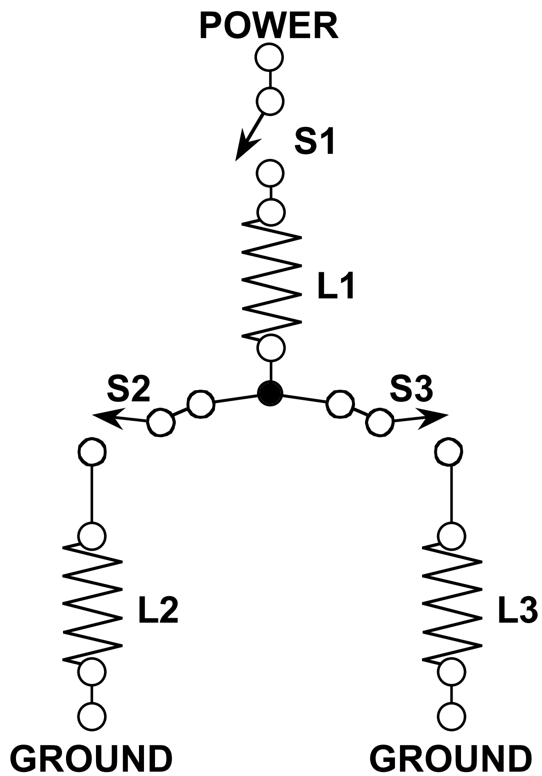
Double Ground Dome Topograph
(“Ground Dome”) …



<u>SNEAK POSSIBILITIES/CLUES</u>:

1) S1 open and L1, L2 and/or L3 function desired.
2) S2 open and L2 function desired.
3) S1 and S2 closed and L2 function not desired.
4) S3 open and L3 function desired.
5) S1 and S3 closed and L3 function not desired.
6) Label of S2 does not reflect function of L2.
7) Label of S1 reflects only function of L1 (or L2 or L3.)
8) S2 and S3 open and L1 function desired.

…etc.

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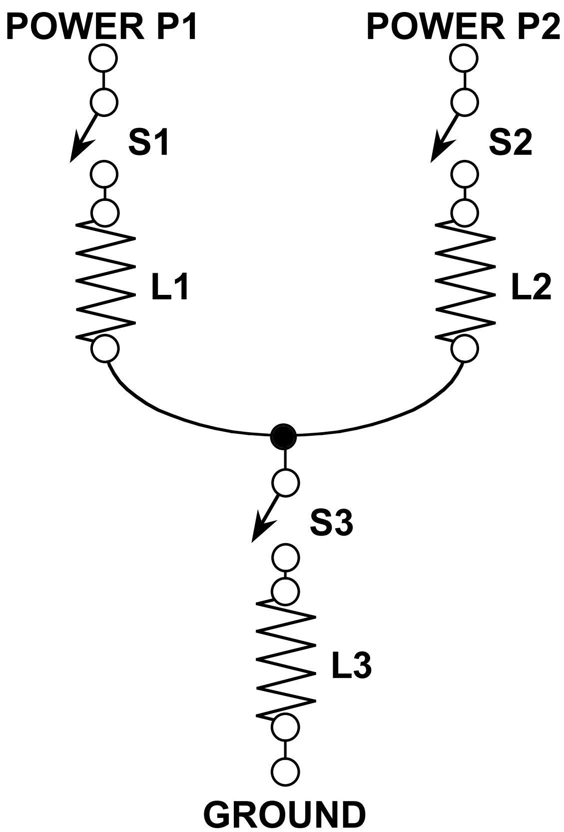
Double Power Dome Topograph
(“Power Dome”) …



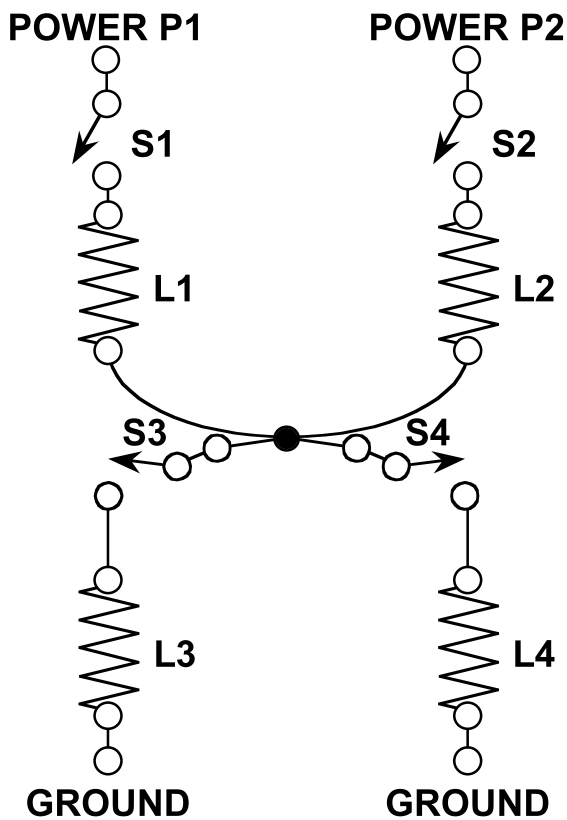
SNEAK POSSIBILITIES/CLUES:

NOTE: P1 may or may not be at the same potential as P2.

1) **S3 open and L1, L2 and/or L3 function desired.**
2) **S1 open and L1 function desired.**
3) **S2 open and L2 function desired.**
4) **Label of S3 reflects only function of L3 (or L1 or L3.)**

…formulate other clues as for prior cases.

Combination Dome Topograph
(“Double Dome”) …



SNEAK POSSIBILITIES/CLUES:

NOTE: P1 may or may not be at the same potential as P2.

1)
2)
3)
4)
⋮
n)

…formulate as for prior cases.

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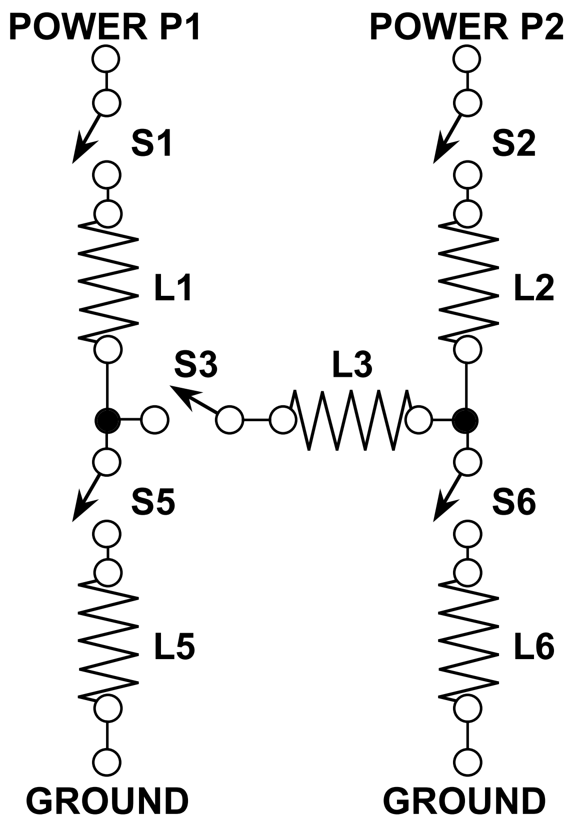
"H" Topograph…



SNEAK POSSIBILITIES/CLUES:

NOTE: P1 may or may not be at the same potential as P2.

1)
2)
3)
4)
n)

…formulate as for prior cases.

"42% of all sneak circuits can be attributed to the 'H' pattern. Such a design configuration should be avoided whenever possible." (Ref. 1.)

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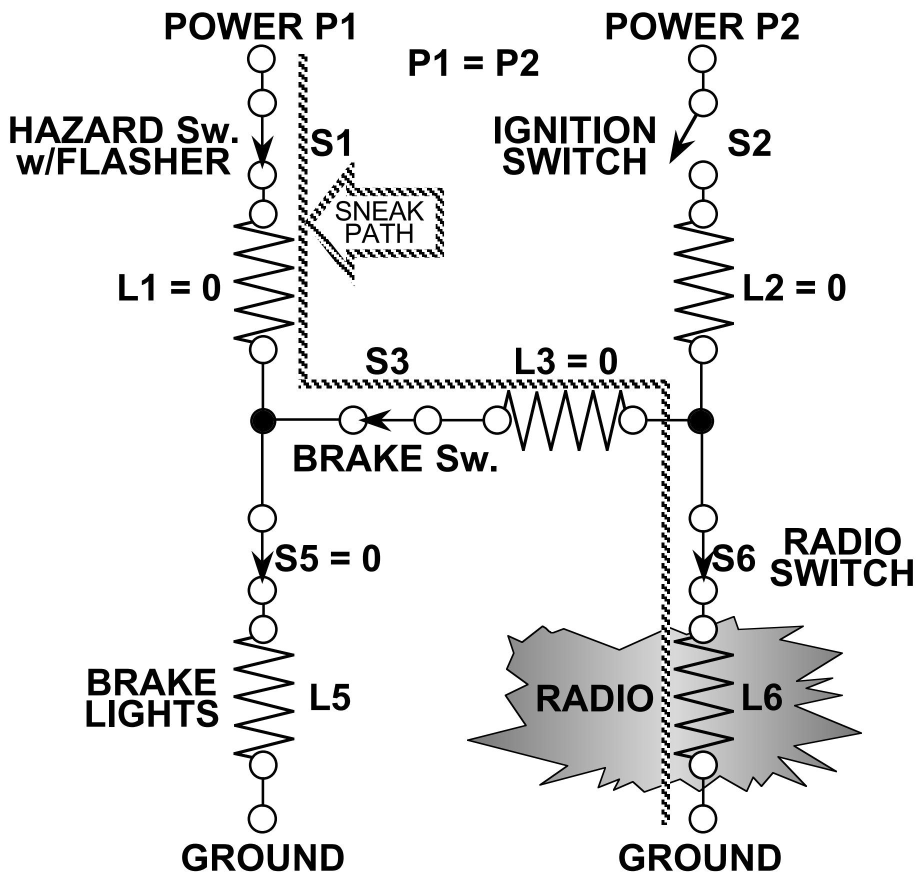
Topographs Applied to Examples

Example 1 (p 5) — “H” Topograph, p 22…



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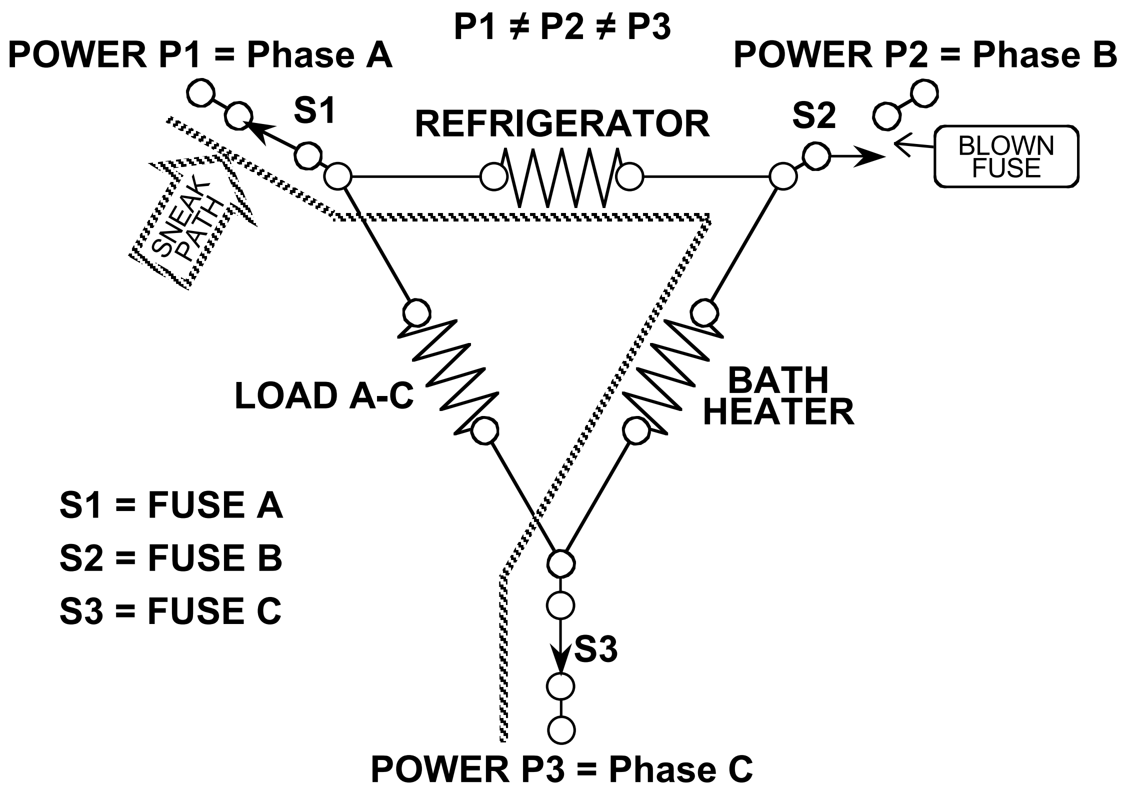
Example 2 (p 7) — New Topograph needed…

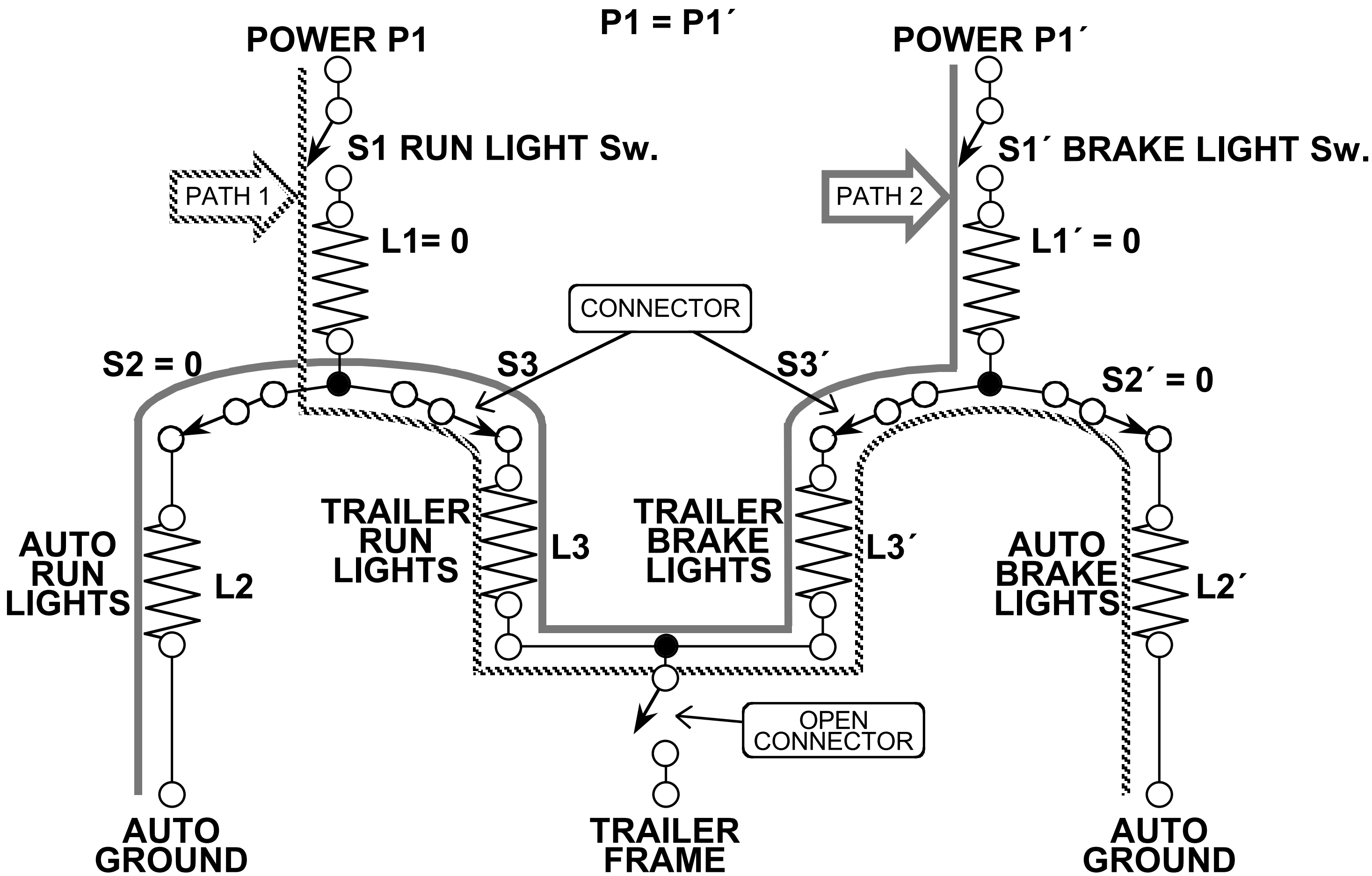


S1 = FUSE A

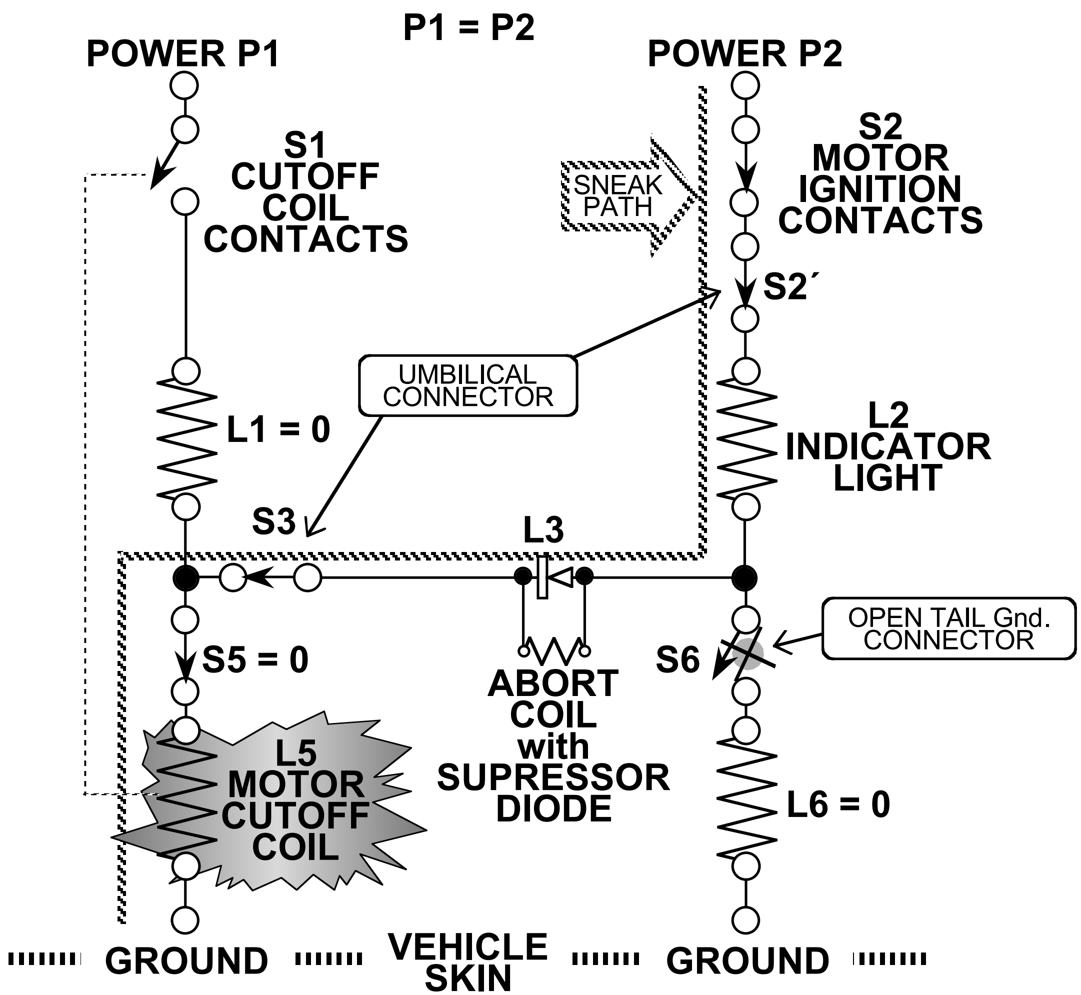
S2 = FUSE B

S3 = FUSE C

Example 3 (p 9) — Two Double Ground Dome Topographs, p 19…



Example 4 (p 11) — “H” Topograph, p 22…



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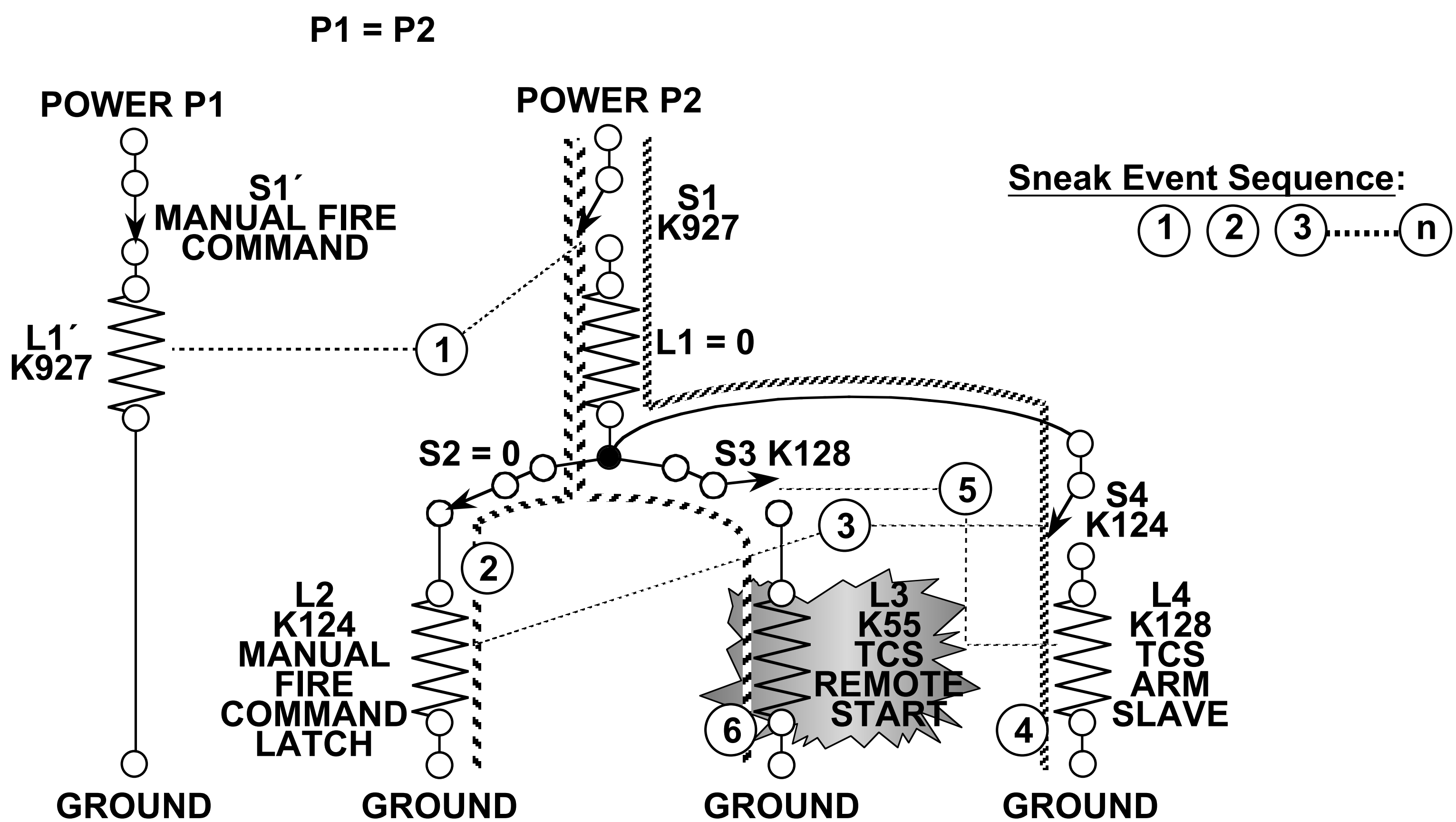
Example 5 (p 13) — Triple Ground Dome plus Single Line Topograph, pp 18 & 19…



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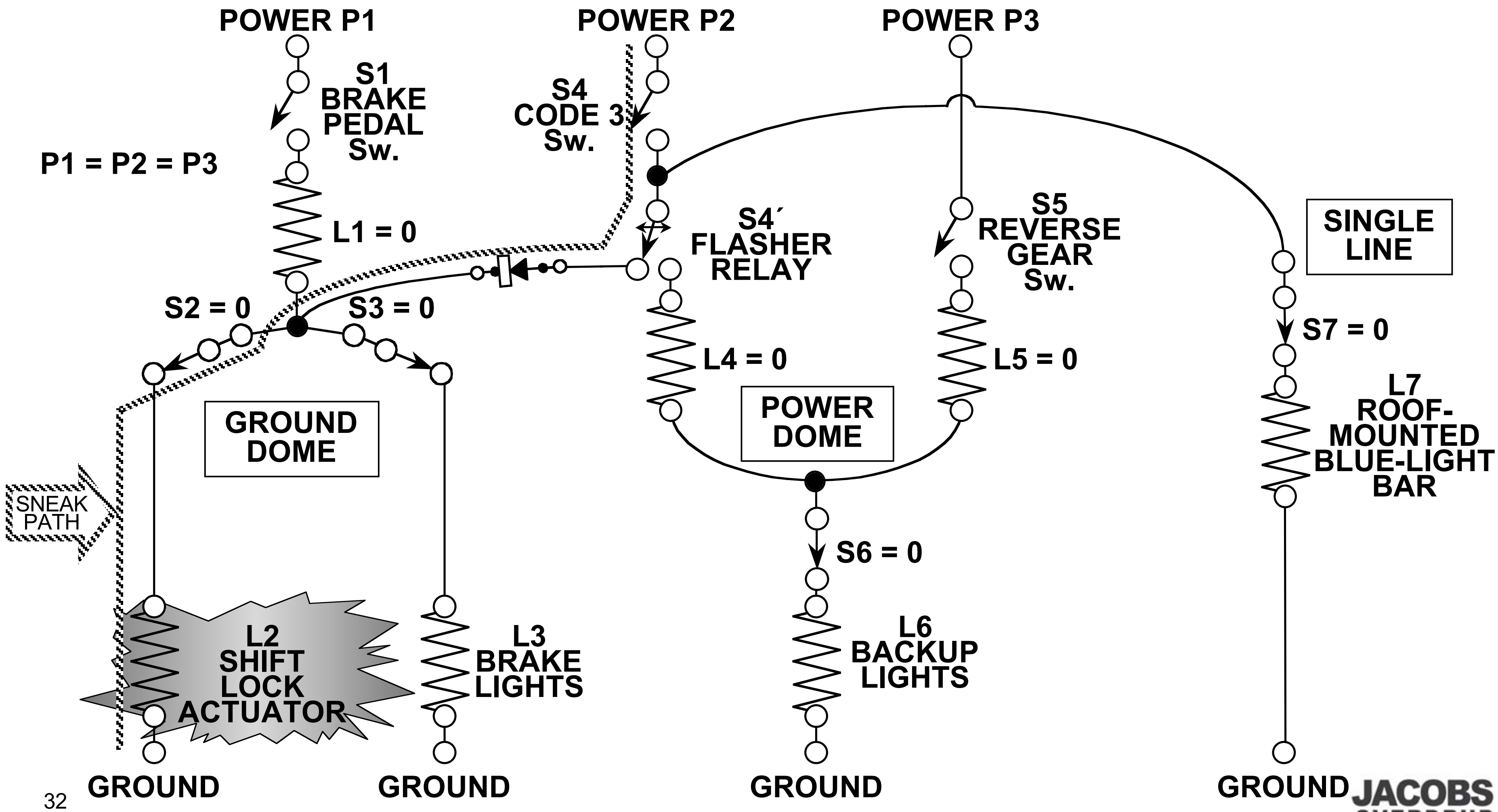
Example 6 (p 15) — Mixed Topographs, pp 21, 22, 23…



"Sneaks" Elsewhere…

OTHER THINGS **than electrical circuits contain *SNEAKS!***

<u>EXAMPLES</u>:

- ***Hydraulic Controls***
- ***Pneumatic Controls***
- ***Mechanical Systems***
- ***Operating Procedures***
- ***Software***
- ***…etc…***

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Final Comments…

- True sneak circuits are designed-in and built-in — they do not result from component faults or failures.
- Sneak circuits abound: control circuits, power distribution circuits, monitoring/measurement circuits…
- Sneak search methods are largely inductive. The topographical comparison method, most prevalent in the literature, is most easily applied after a malfunction has been recognized!
- Sneaks afflict other-than-electrical systems…

  Hydraulic
  Mechanical
  Procedural
  …etc…

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References…

1. Rankin, J. P., "Sneak Circuit Analysis," Nuclear Safety, Vol. 14, No. 5, Sept.-Oct. 1973
2. Hill, E. J., "Sneak Circuit Analysis of Military Systems," Proceedings of the Second International System Safety Conference, July 1975
3. Rankin, J. P., "Identification of Common Cause Failures in Instrumentation and Control Systems," Hazard Prevention, Vol. 18, No.1 Jan.-Feb. 1982
4. Naval Sea Command, "Contracting and Management Guide for Sneak Circuit Analysis," NAVSEA-TE001-AA-GYD/SCA, Sept. 1980
5. Browne, Jack, Jr., "Benefits of Sneak Circuit Analysis for Defense Programs," Proceedings of the Third International System Safety Conference, Oct. 1977
6. Buratti, D. L, and S. G. Godoy, "Sneak Analysis Application Guidelines," RADC-TR-82-179, June 1982
7. Mason, J. F., "An Analysis of Three Mile Island," IEEE Spectrum, Vol. 16, No. 11, Nov. 1979
8. Caldwell, S. H., "Switching Circuits and Logical Design," Wiley & Sons 1979
9. Young, J. R., "Report documenting ODI's investigation of a sudden acceleration incident …in Minneapolis, Minnesota on December 4, 1998," US DoT, National Highway Traffic Safety Administration, Jan. 12, 1999 (See also Supplemental Report, Mar.18 1999.)

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Additional Reading…

- Clardy, R. C., “Sneak Circuit Analysis Development and Application,” 1976 Region V IEEE Conference Digest, April 1976
- Clardy, R. C., “Sneak Circuit Analysis; An Integrated Approach,” Proceedings of the Third International System Safety Conference, Oct. 1977
- Godoy, S. G. and G. J. Engels, “Sneak Circuit and Software Sneak Analysis,” Journal of Aircraft, Vol. 15, Aug. 1978
- McRae, P. D., Jr. “Sneak Analysis & System Safety — The Fit & Benefit,” Proceedings of the Fifth International System Safety Conference, July 1981

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