Impact of Frequency Deviations on Protection Functions

Ilia Voloh Dale Finney Mark Adamiak
General Electric Co.

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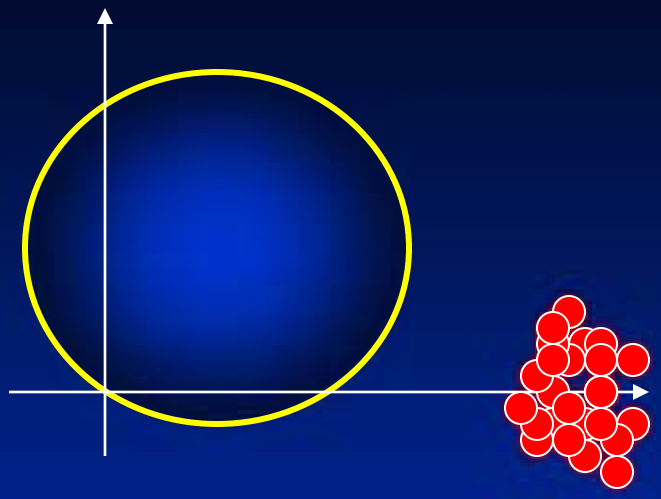
Outline

- **Problem statement**
- **Digital measurements and frequency deviations**
- **Impact on simple protection functions**
- **Distance protection**
  - Self-and cross-polarized
  - Memory-polarized
  - Testing
- **Conclusions**

Problem Statement



During major system events:

- **Under heavy load including depressed voltage, and**
- **Frequency considerably different from nominal, and/or**
- **Frequency changing**

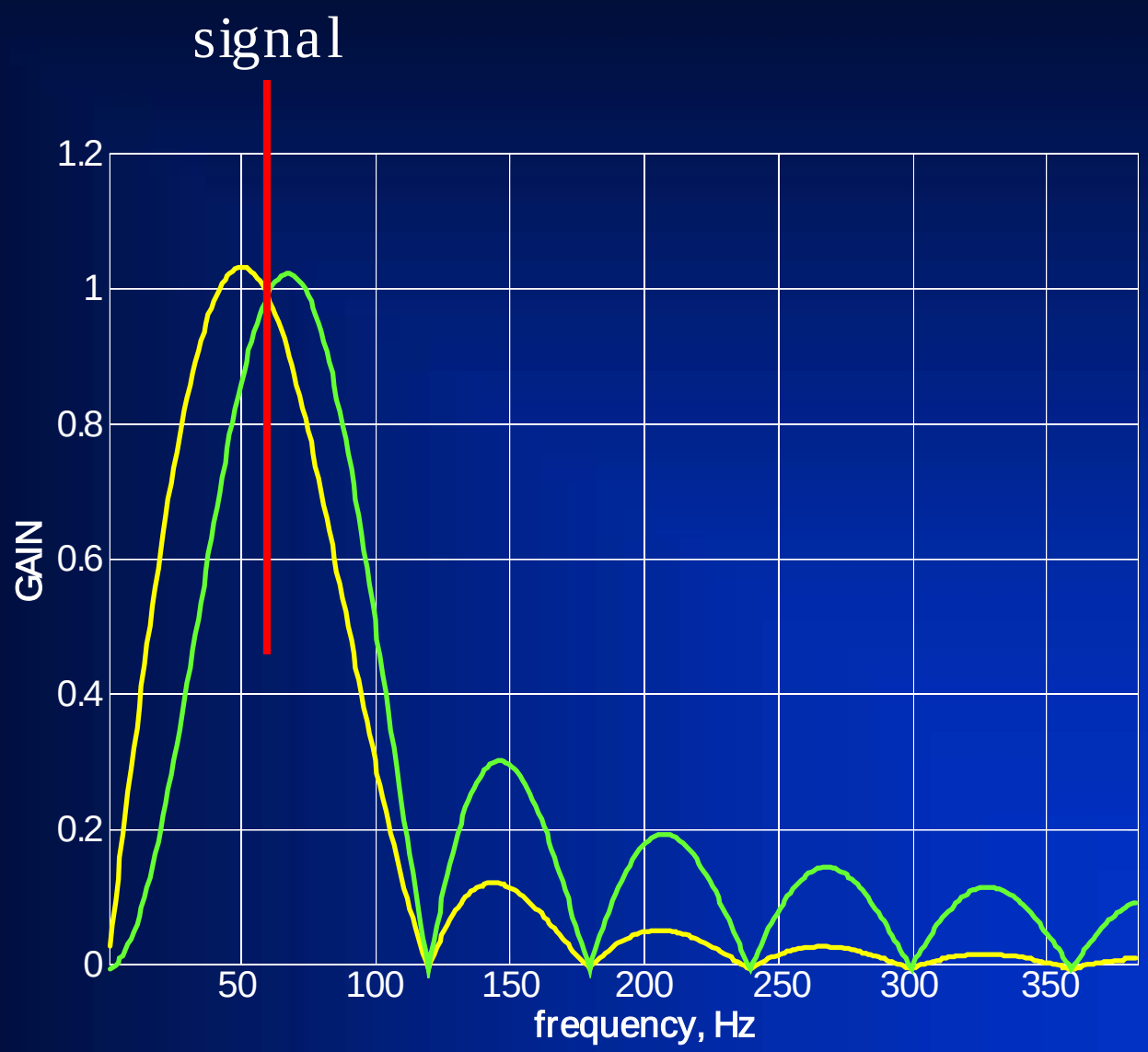
Ensure the following:

- Security, to give remedial schemes time to operate
- Some level of dependability, to maintain asset and system protection

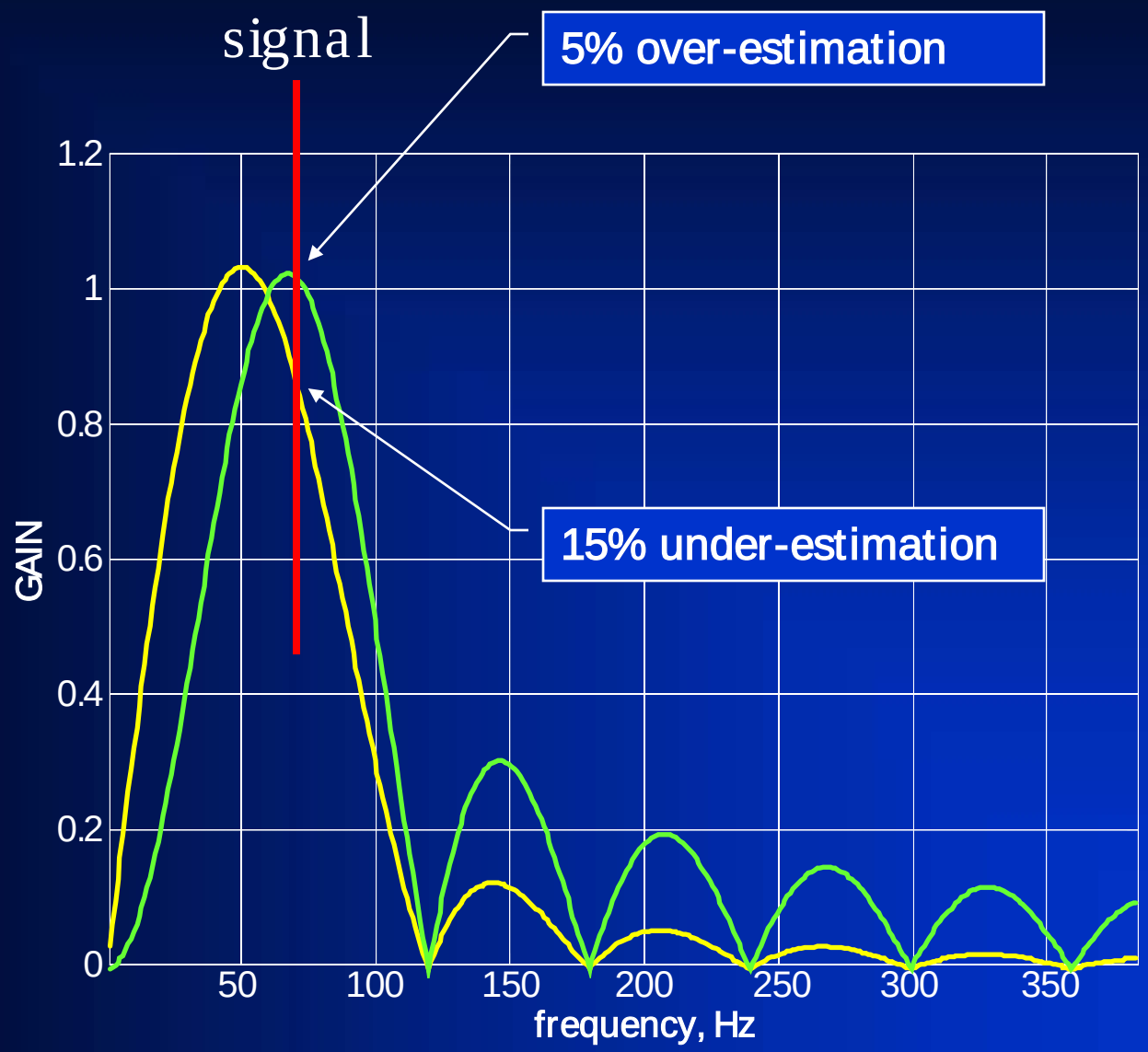
Impact of Frequency Deviations

- **Why is it a problem?**
  - Most protection functions respond to information in the actively driven signal components (fundamental frequency)
  - When the fundamental changes, some accuracy is lost
- **Is it a unique issue with microprocessor-based relays?**
  - No, all technologies are affected
  - Microprocessor-based relays can correct for off nominal frequencies

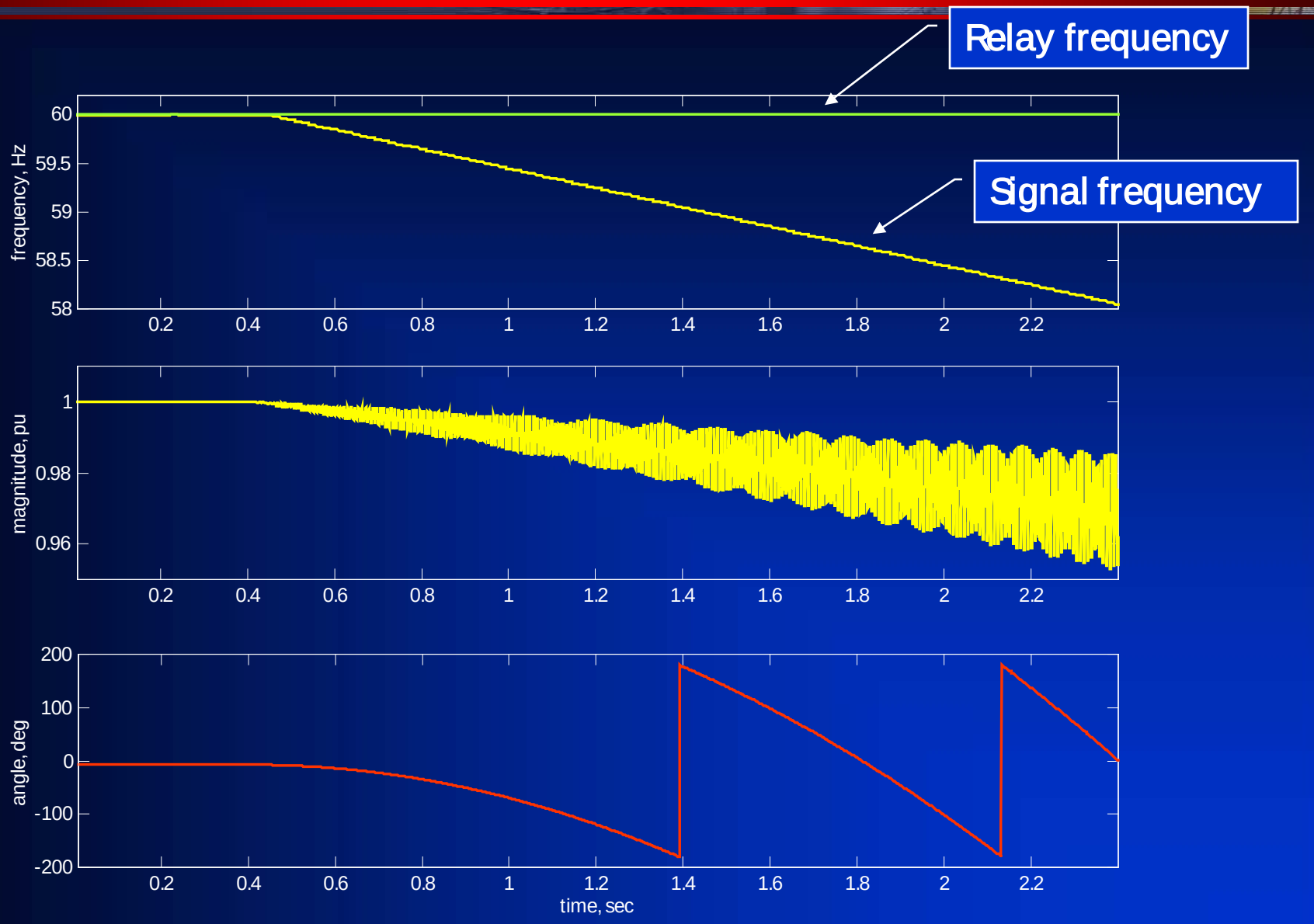
Phasor Estimation as Filtering



Filters are Frequency-dependent



Example – Frequency Ramp without tracking



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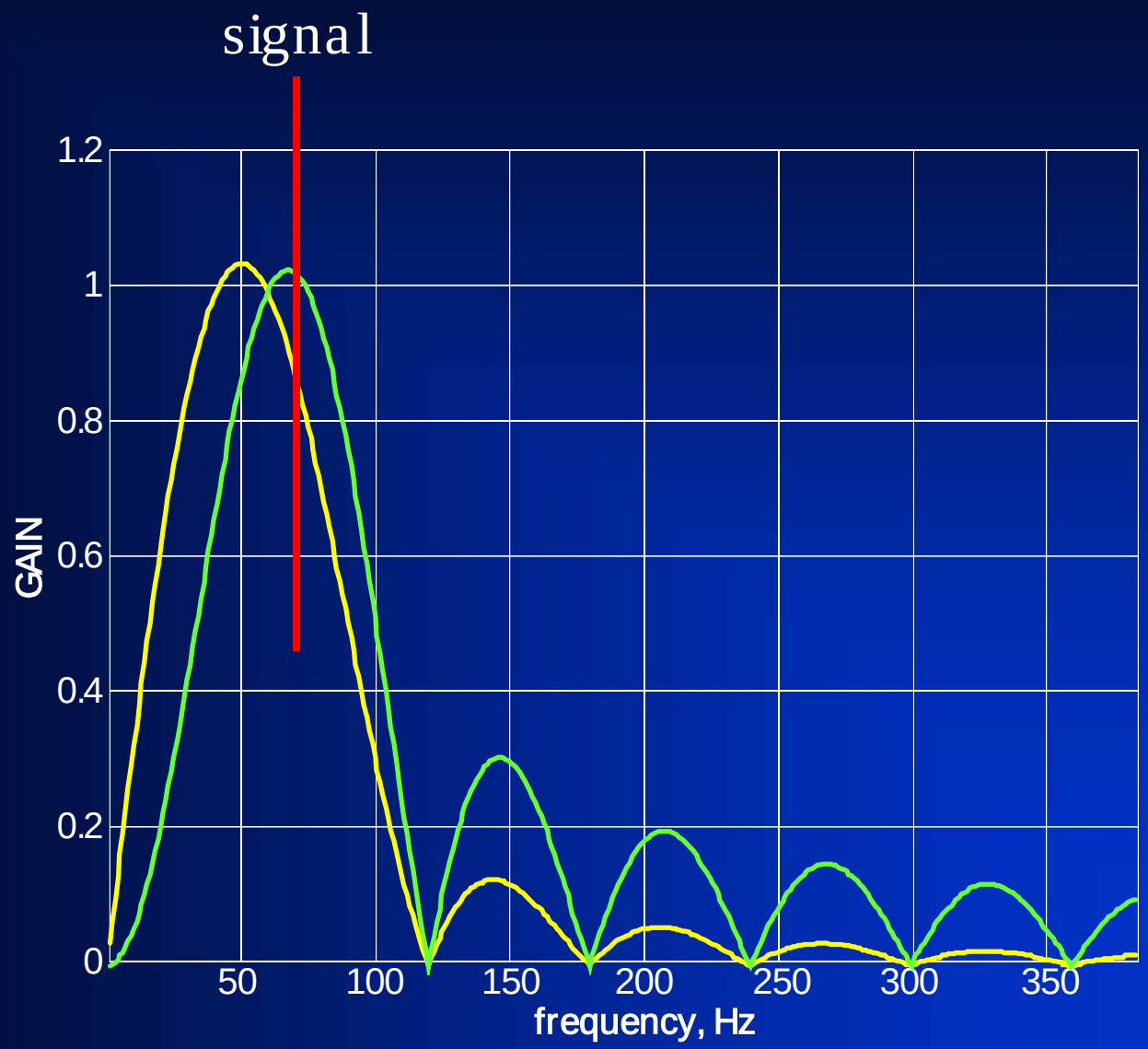
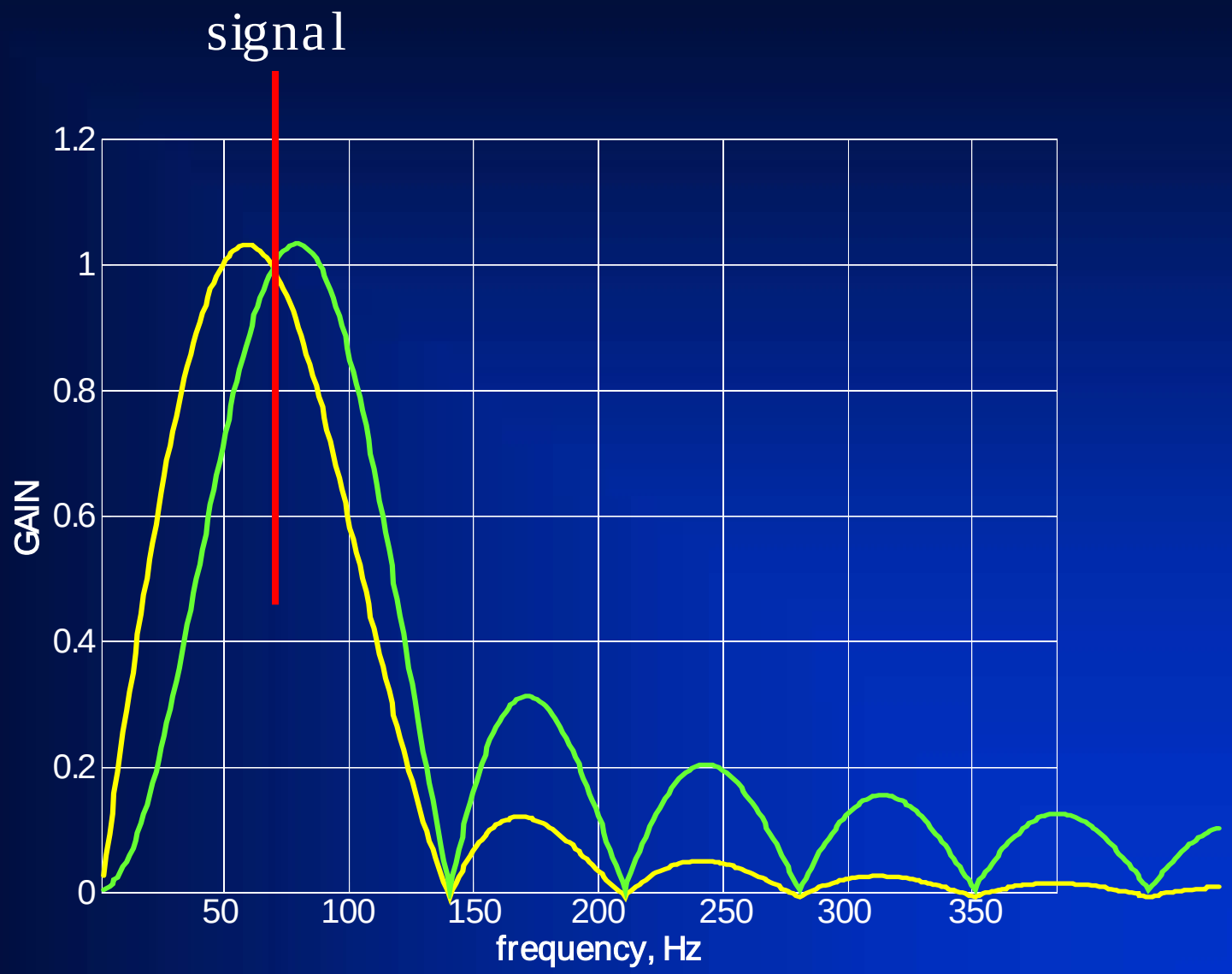
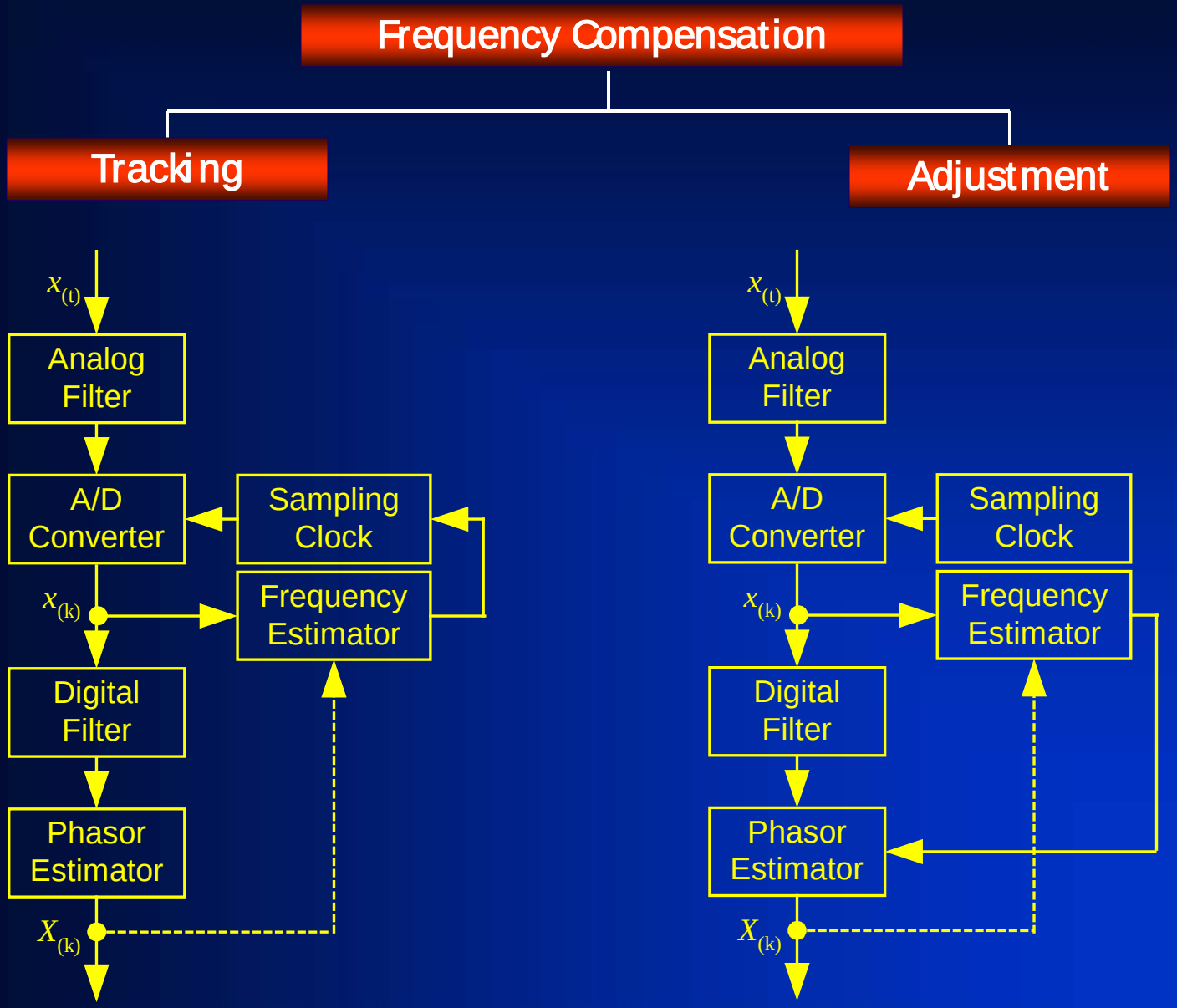


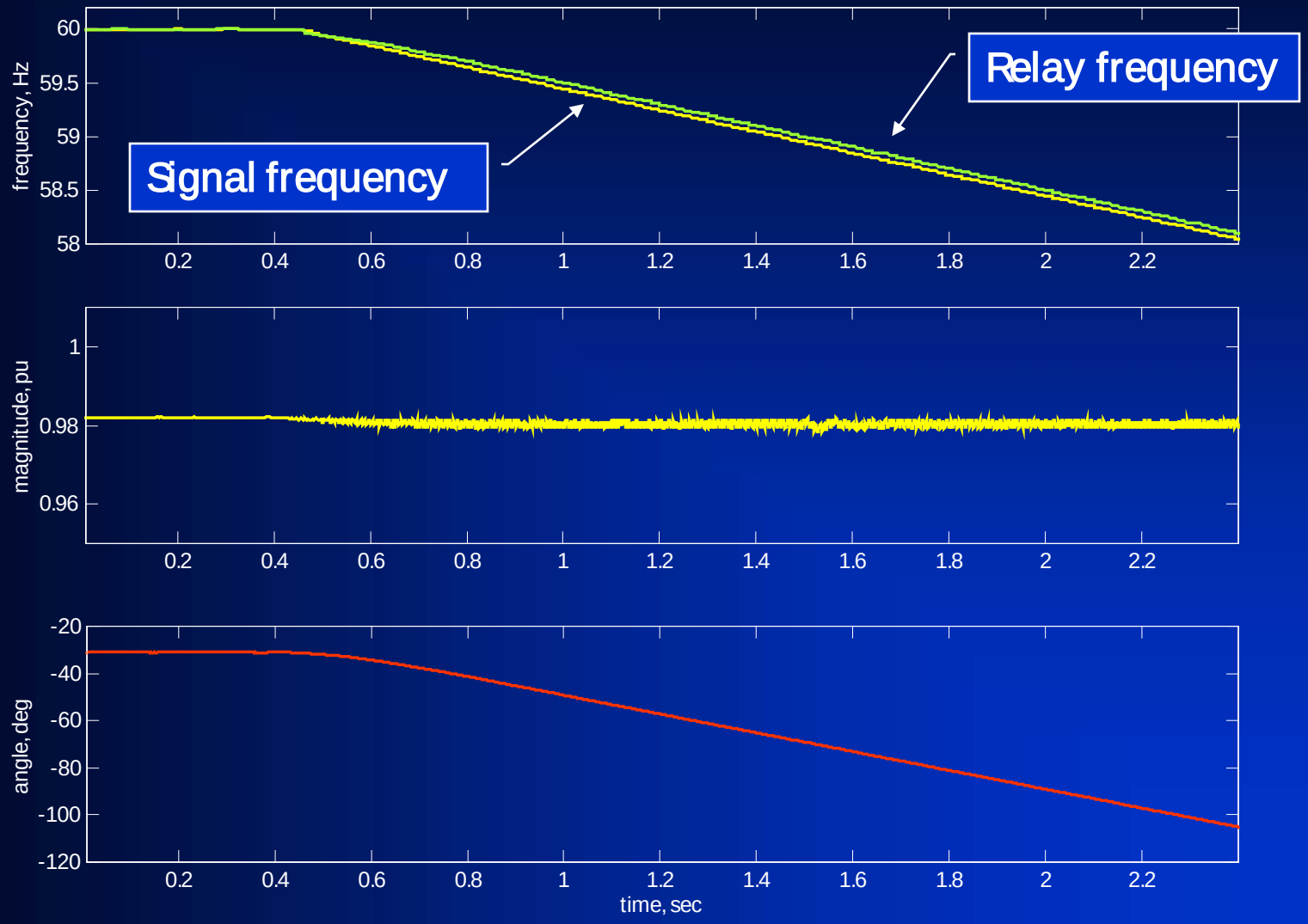
Accuracy Recovered



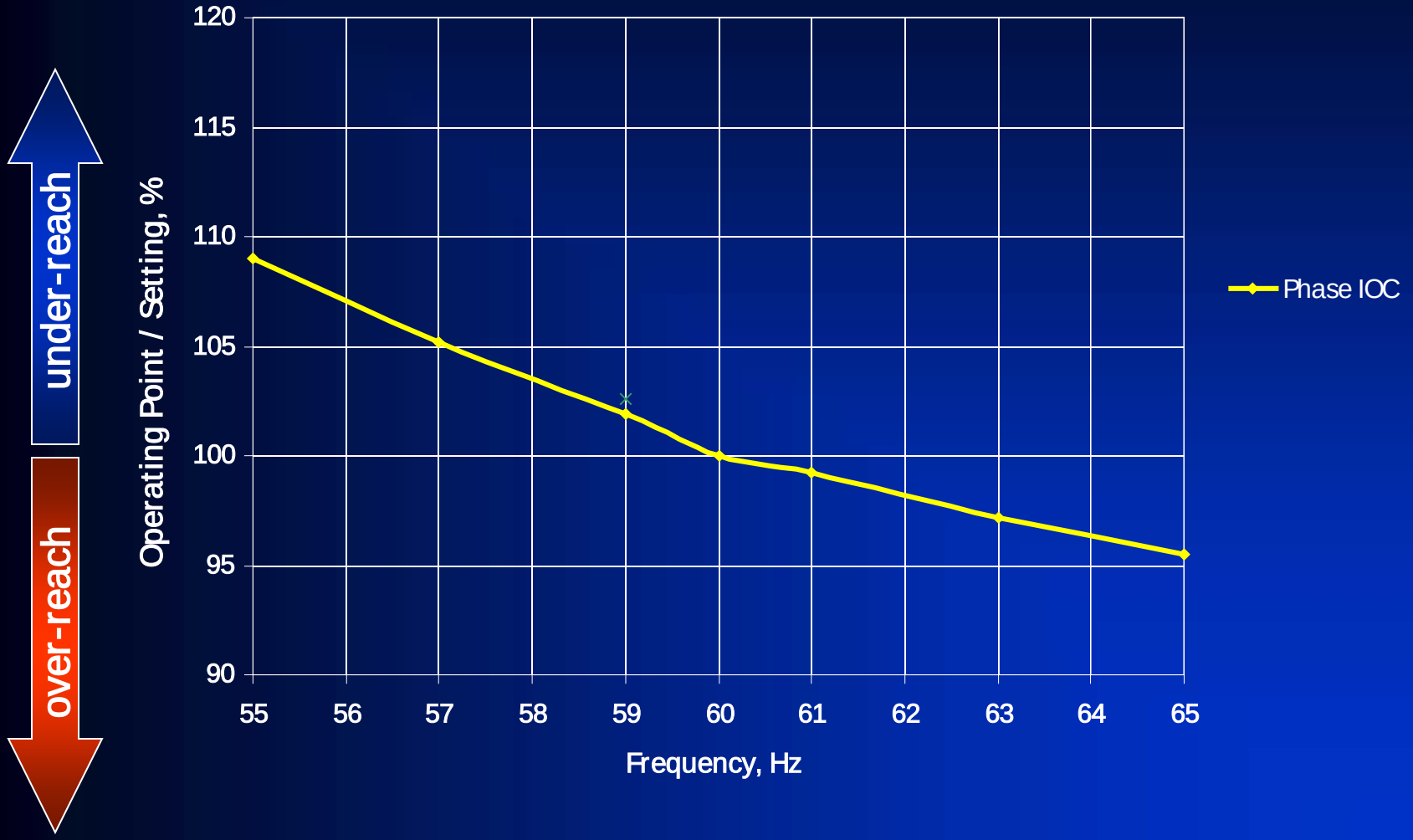
Eliminating Frequency Errors



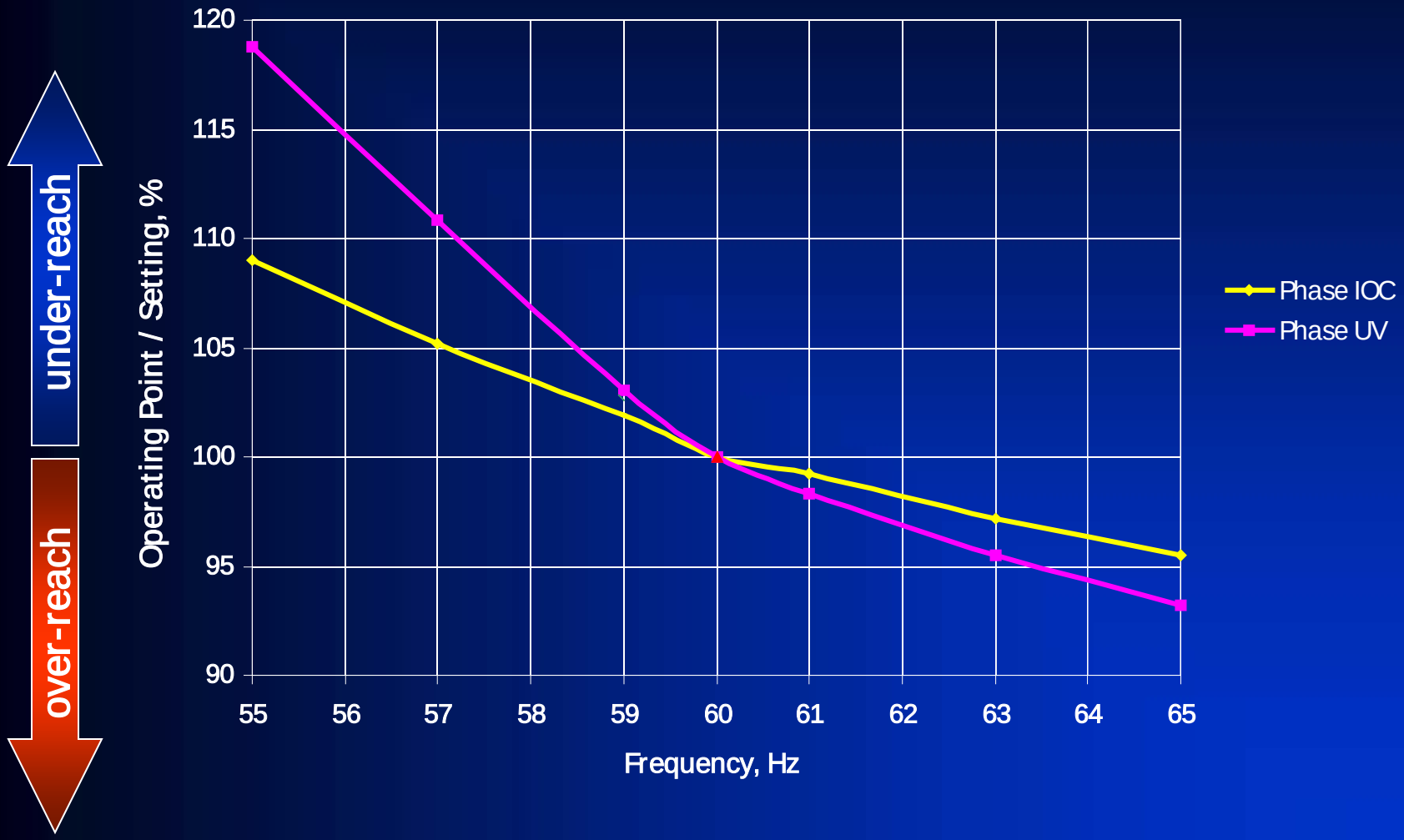
Example – Frequency Ramp with Tracking



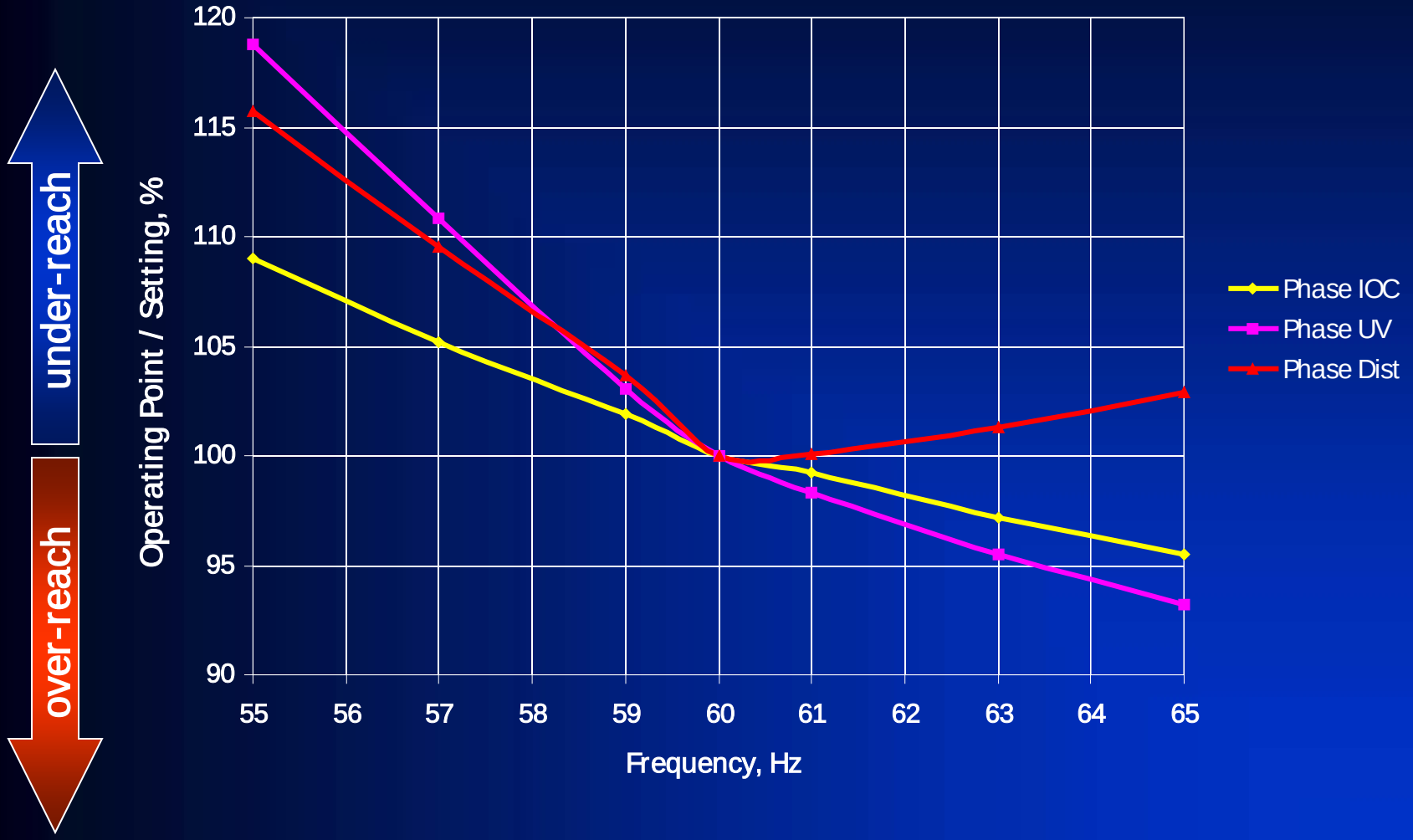
Impact on Simple Protection Functions (50/51)



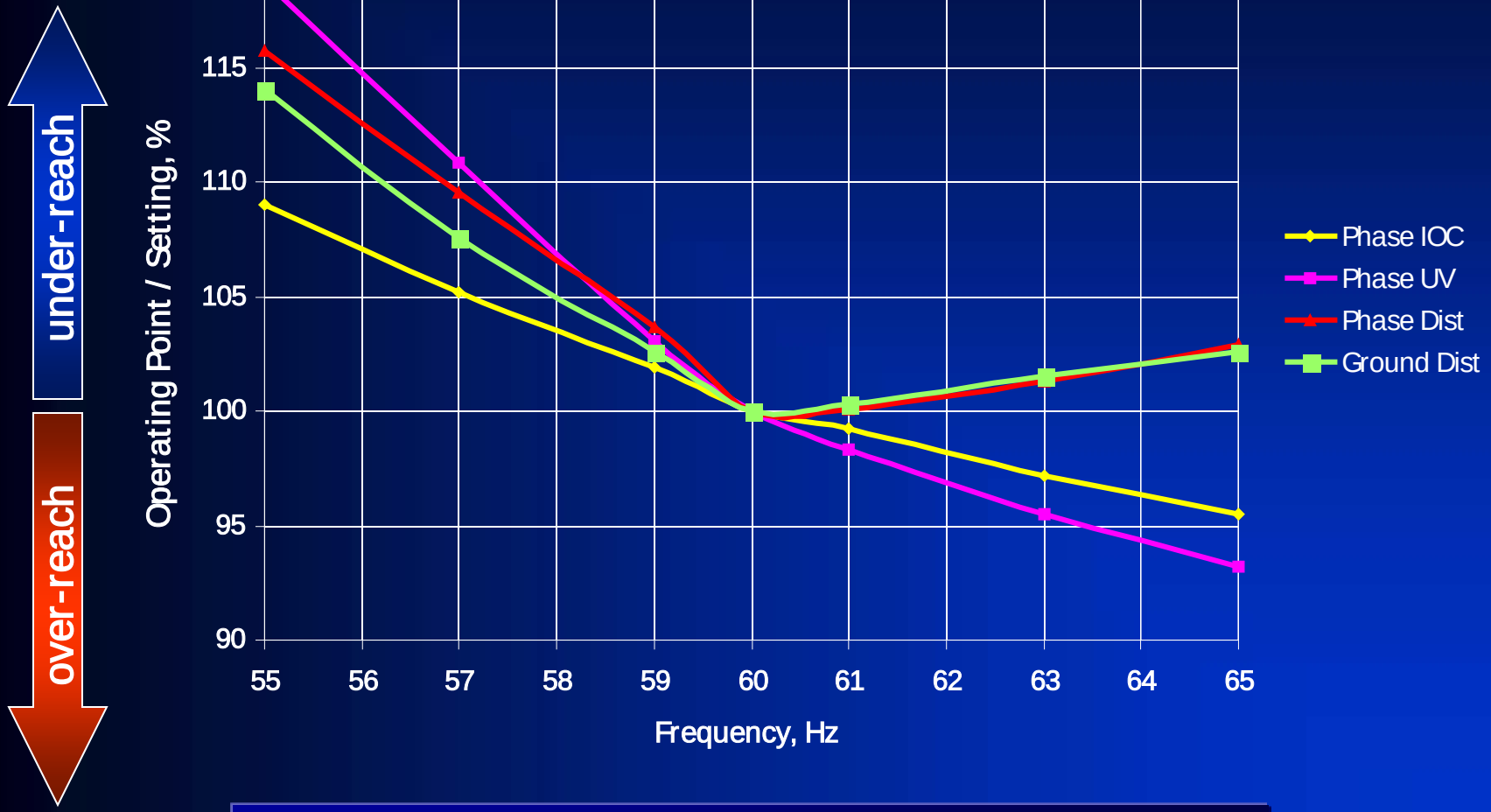
Impact on Simple Protection Functions (27/59)



Impact on Simple Protection Functions (21P)

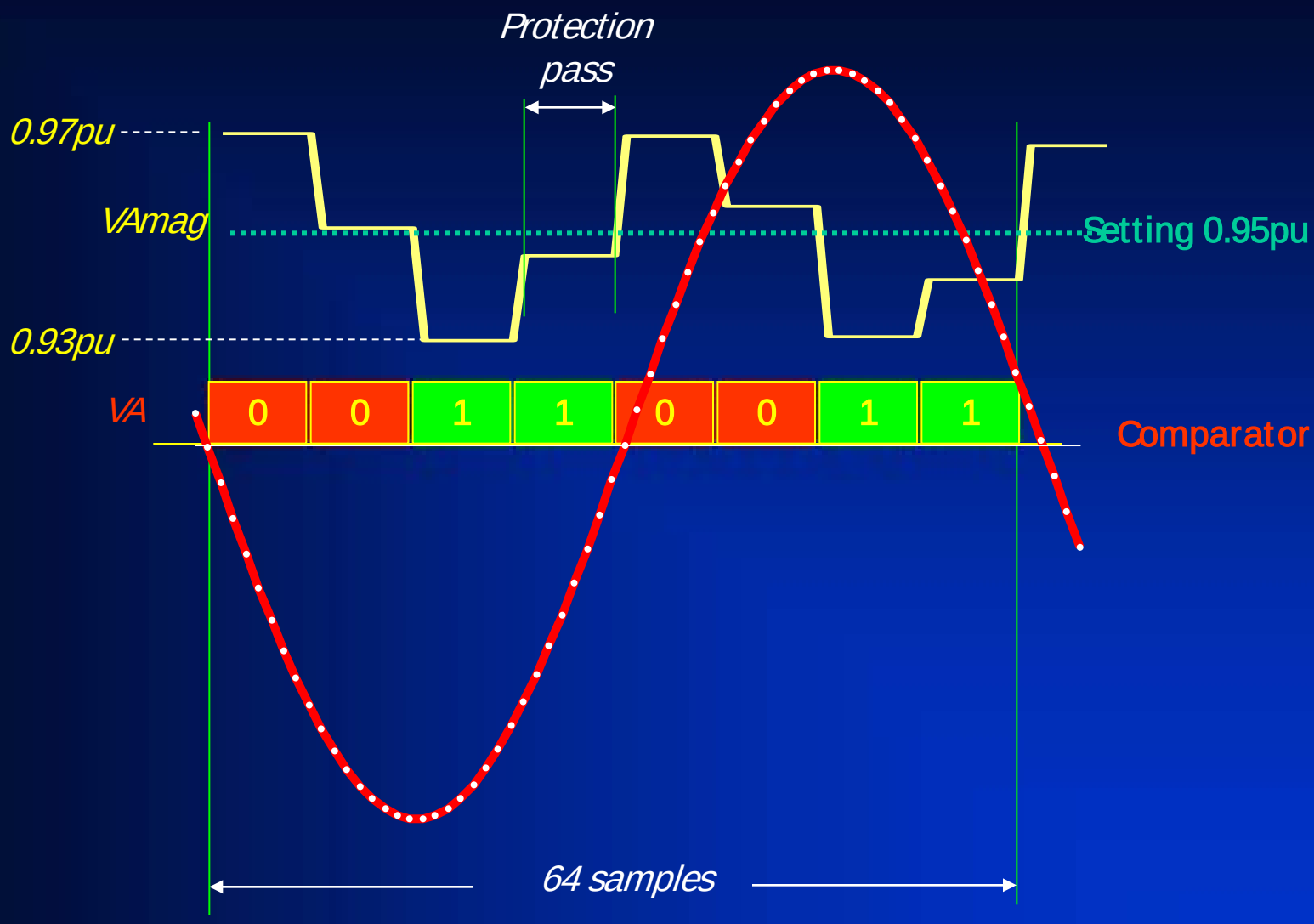


Impact on Simple Protection Functions (21G)



Few percent accuracy loss per each Hz of difference between relay and signal frequency

Relay Comparators and Security Counts (UV)



"Security counts" and similar measures reduce impact of the magnitude ripple on comparators during frequency excursions

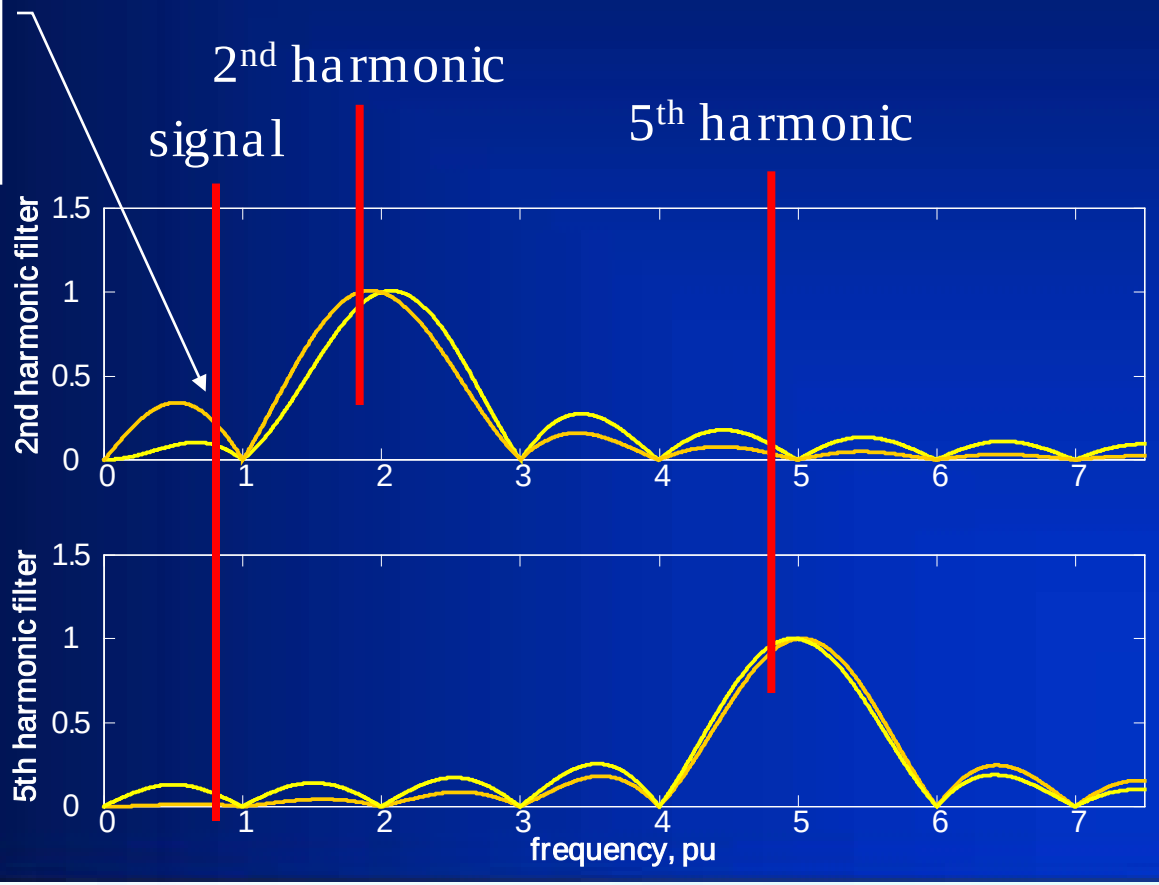
Takeaways

- Microprocessor-based relays less prone to frequency errors
- Errors in the range of up to few percent per each Hz of frequency difference
- On modern relays errors eliminated by frequency tracking/compensation
- During fast frequency ramps tracking will typically lag – some frequency errors remain

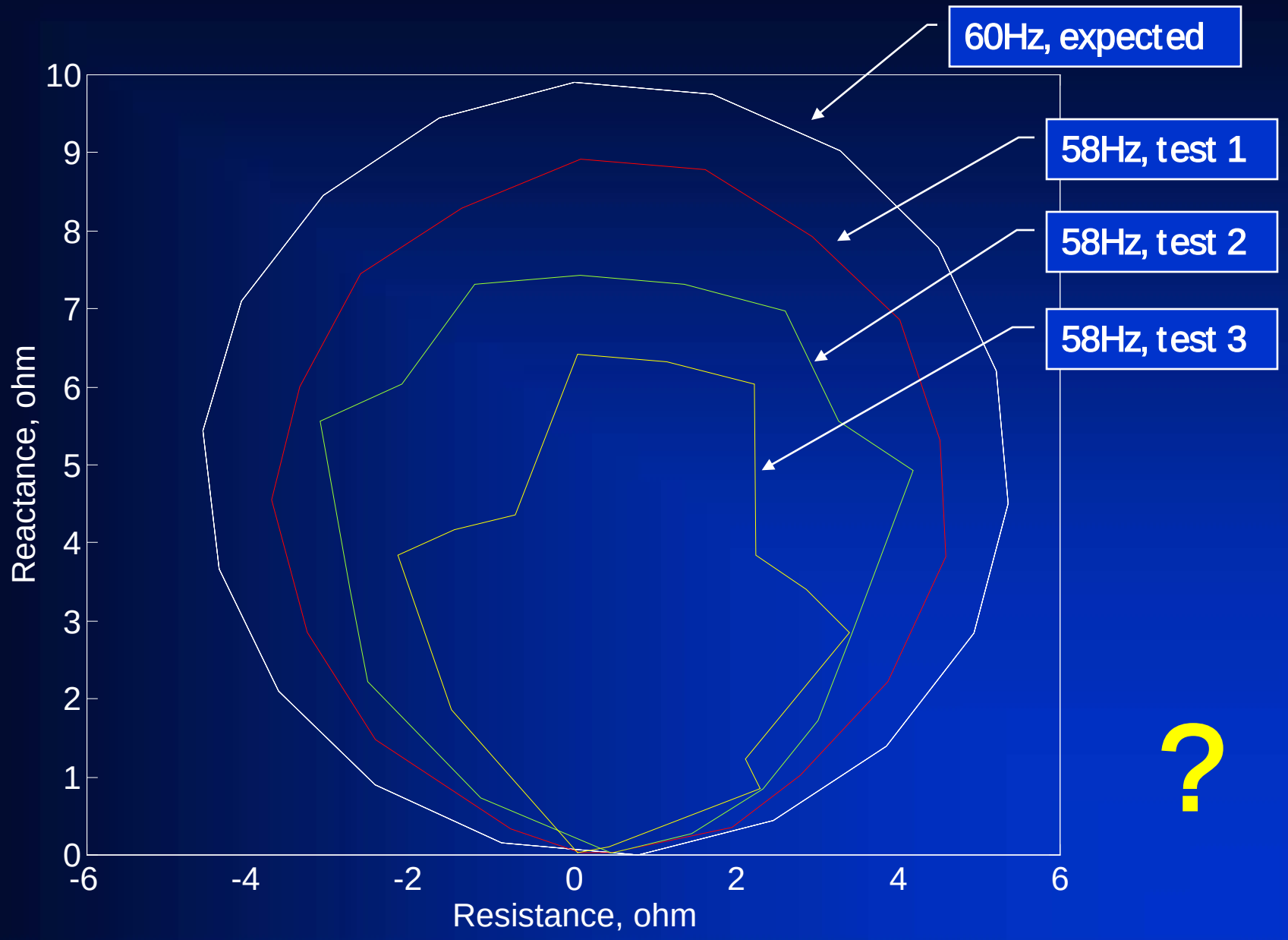
Impact on Advanced Protection Functions (87)

- Differential principle immune
- Line dif relays must use the same frequency
- Harmonic restraint may face some problems

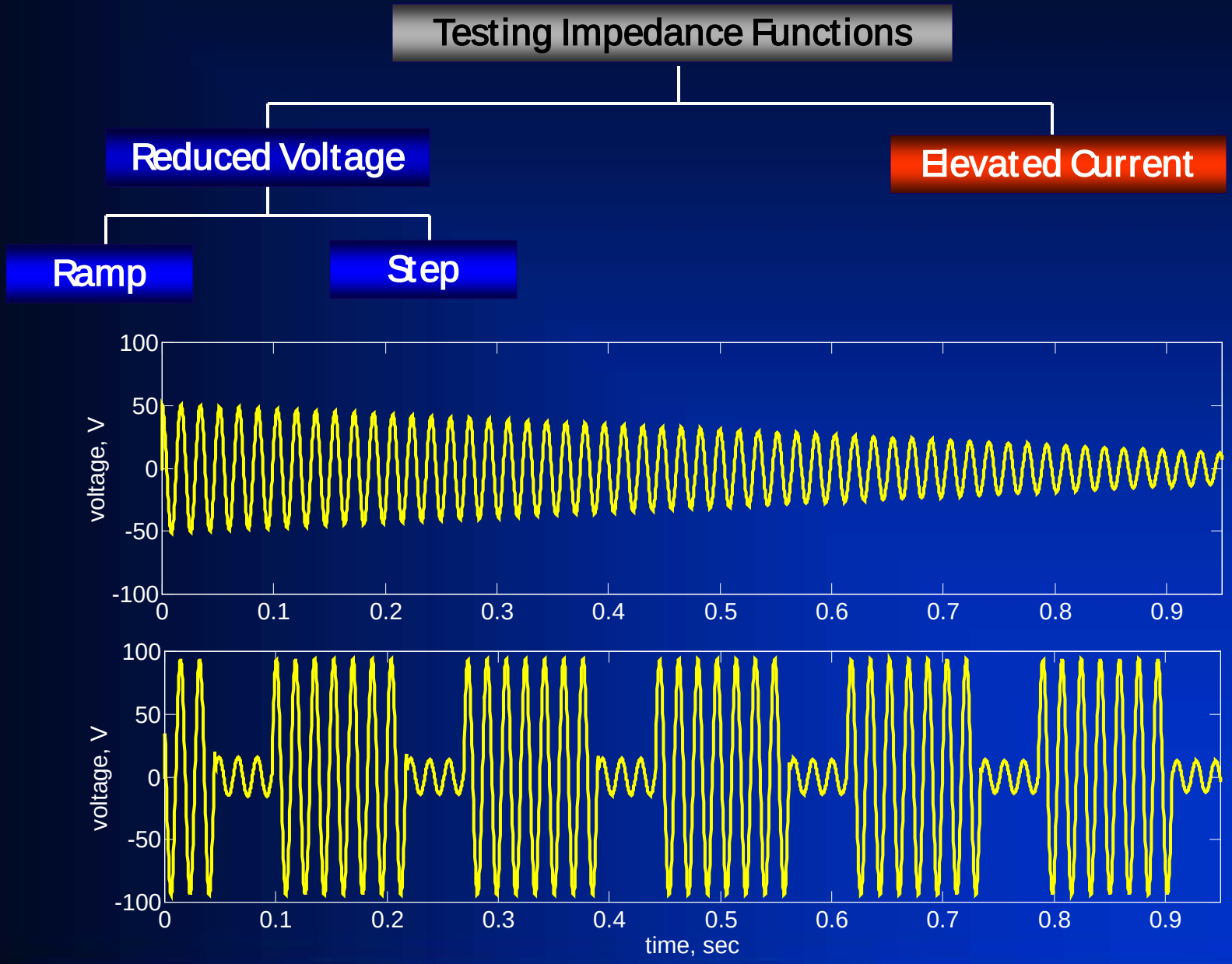
Fundamental component “leaks” into harmonics



Impact on Advanced Protection Functions (21)



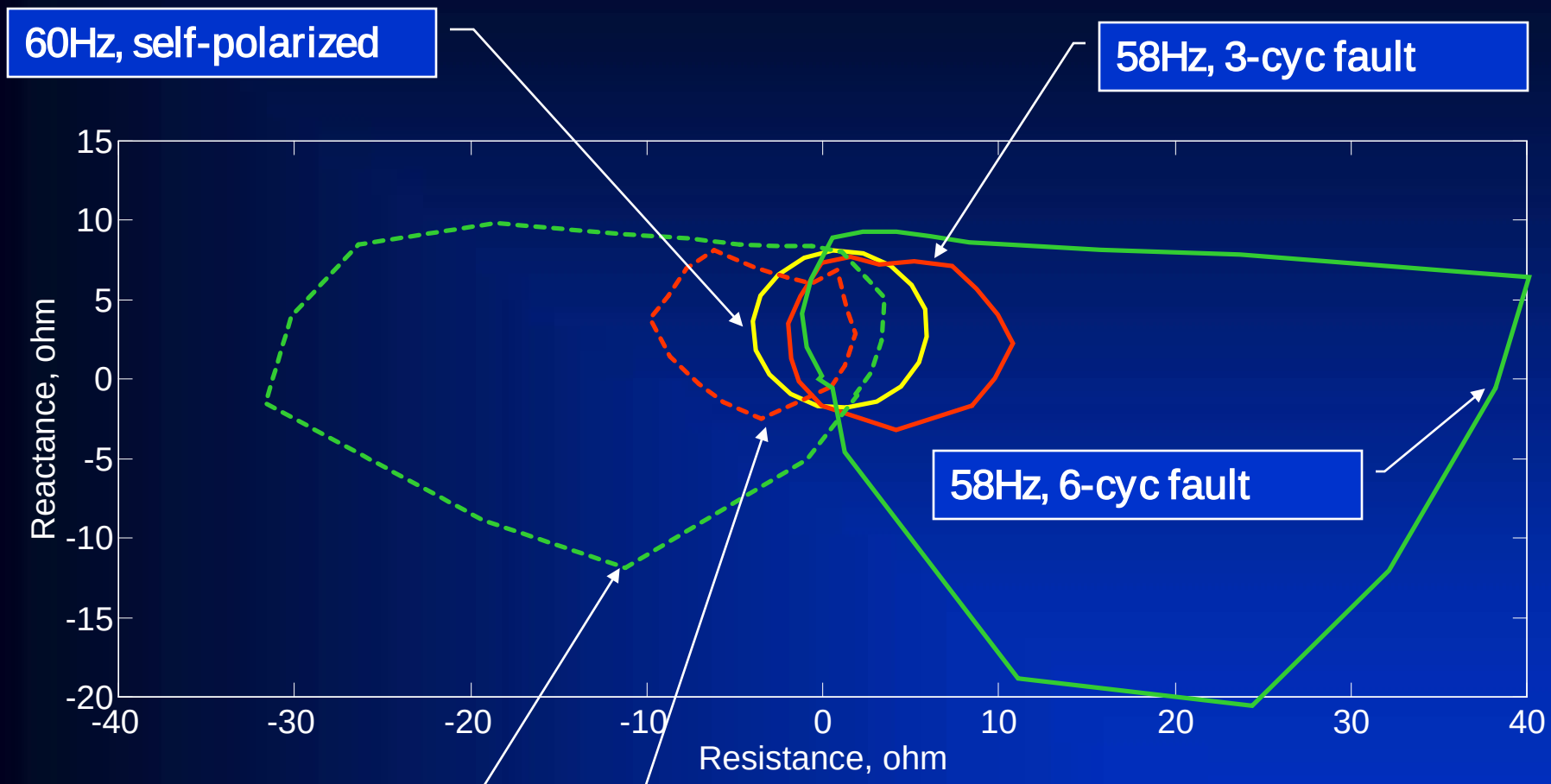
Testing Impedance Functions



Testing – Recommendations

- Apply known and trusted test methods, do not troubleshoot test scripts while testing relays
- Educate yourself re impedance functions and impact of frequency before testing
- Be careful about test subject: test self- and memory-polarized modes separately
- Test the ability to track frequency separately from distance functions
- Do not apply step changes in frequency during short circuit tests

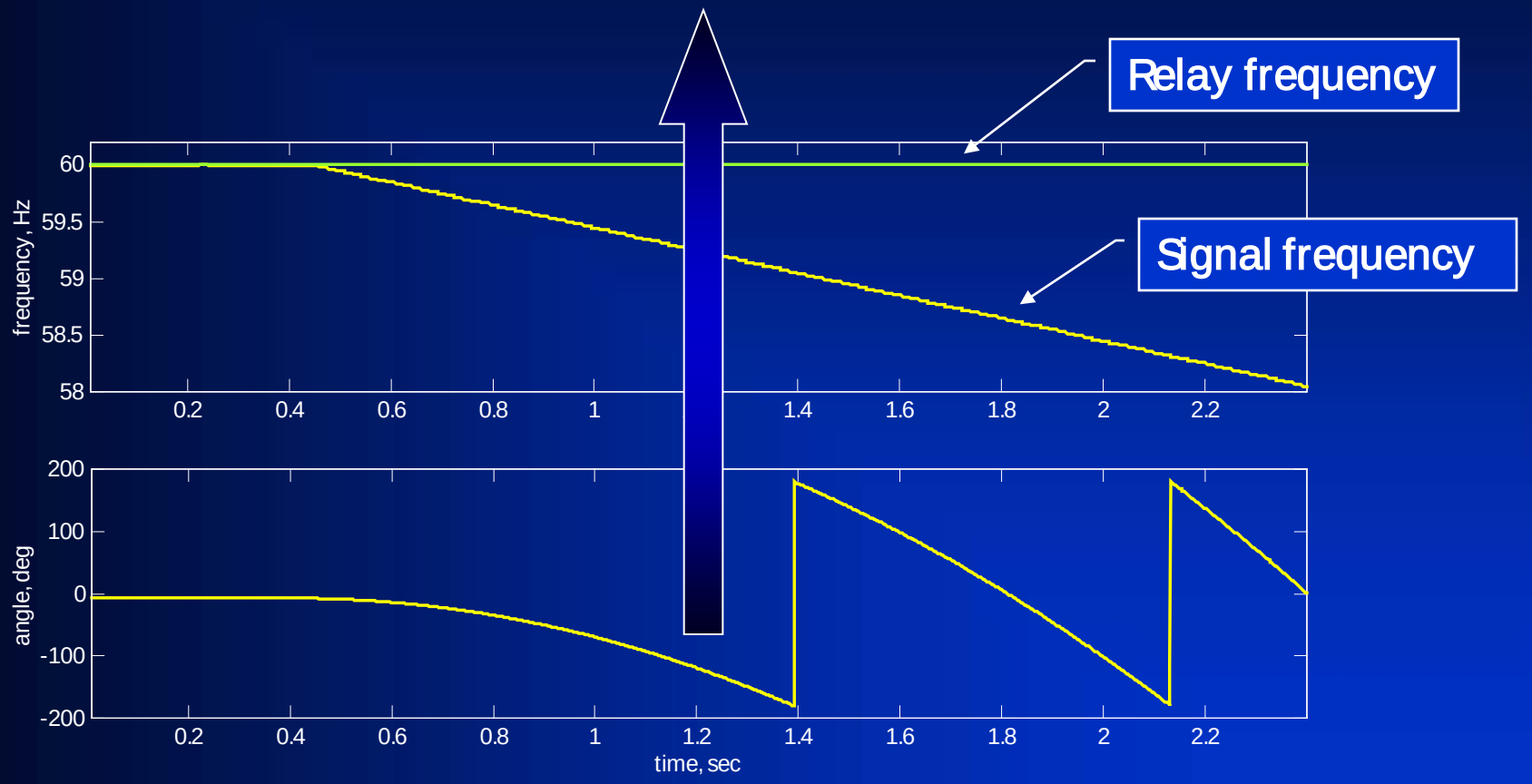
Memory-polarized mho (tracking off)



Serious load encroachment situation

Understanding Impact of Memory Polarization

Dynamic mho: $I_{AG}Z_{REACH} - V_A$ vs. V_{1MEM}

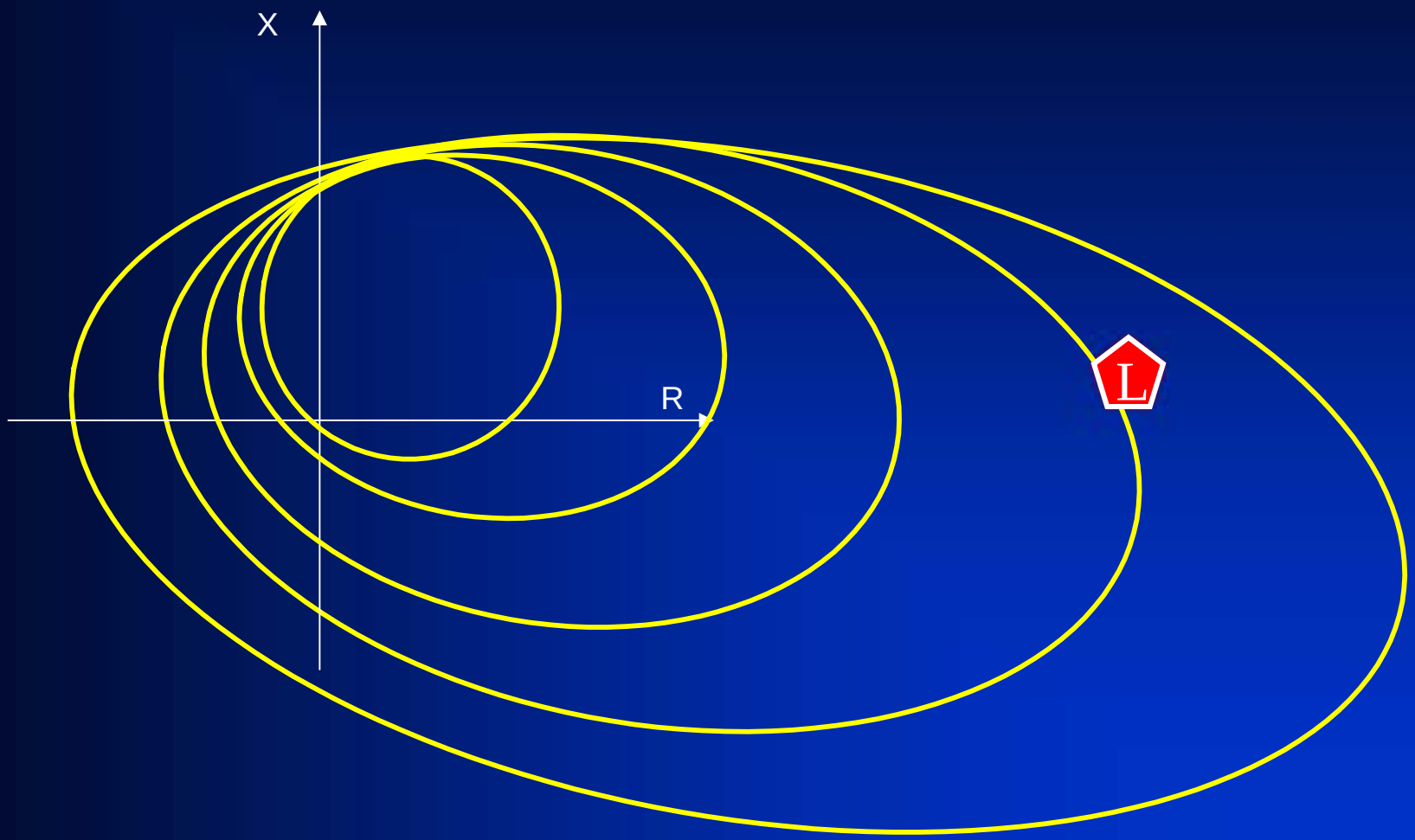


Once the memory kicks in, any memory-polarized function will operate given enough time

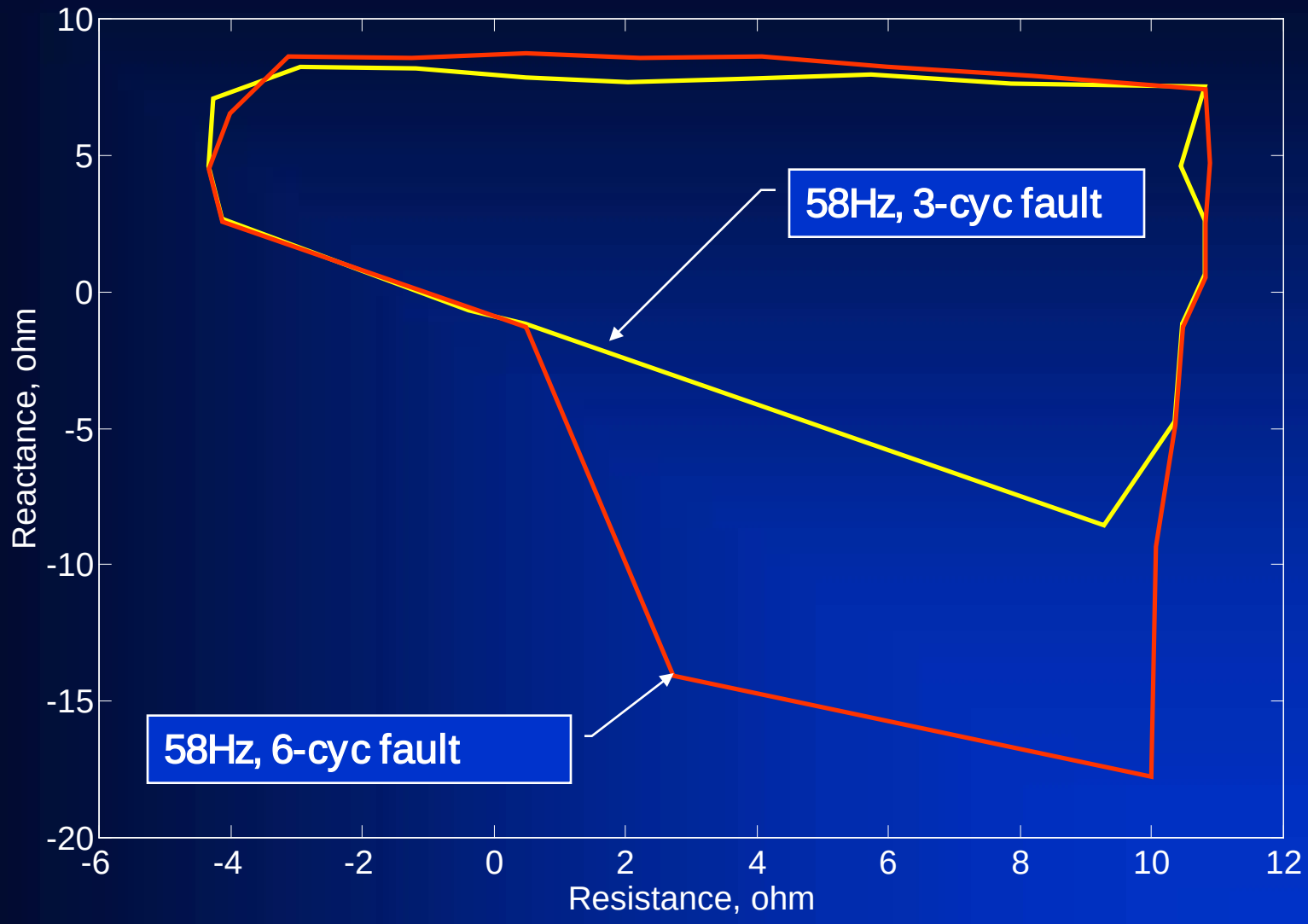
Sample Ground Distance Mho Function

Dynamic mho:	$I_{AG}Z_{REACH} - V_A$	vs.	V_{1MEM}
Adaptive reactance:	$I_{AG}Z_{REACH} - V_A$	vs.	$I_0 Z_{REACH}$
Neg-seq directional:	$I_2 Z_{DIR}$	vs.	V_{1MEM}
Zero-seq directional:	$I_0 Z_{DIR}$	vs.	V_{1MEM}
Phase selection:	I_0	vs.	I_2

Understanding Impact of Memory Polarization

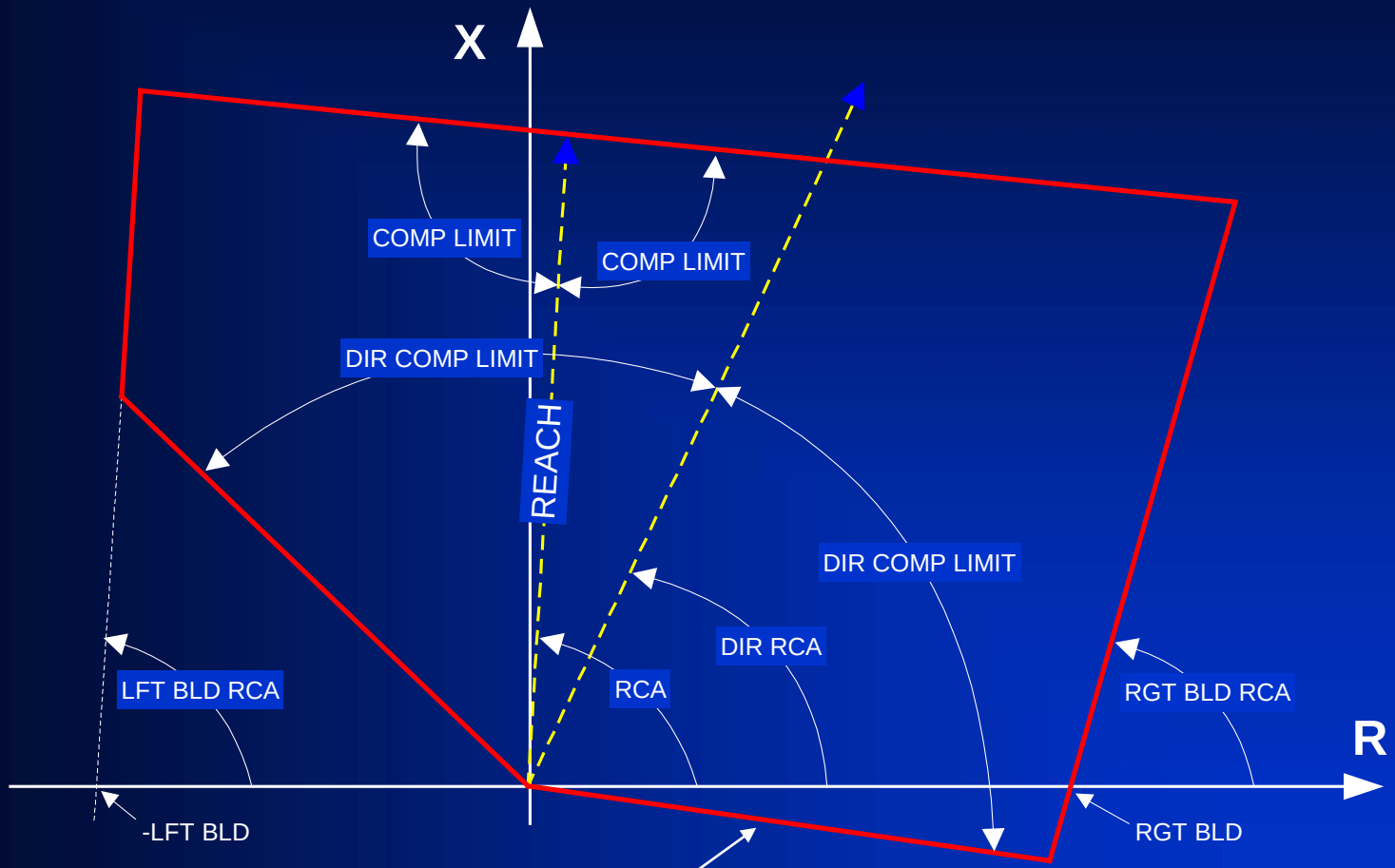


Memory-polarized quad (tracking off)



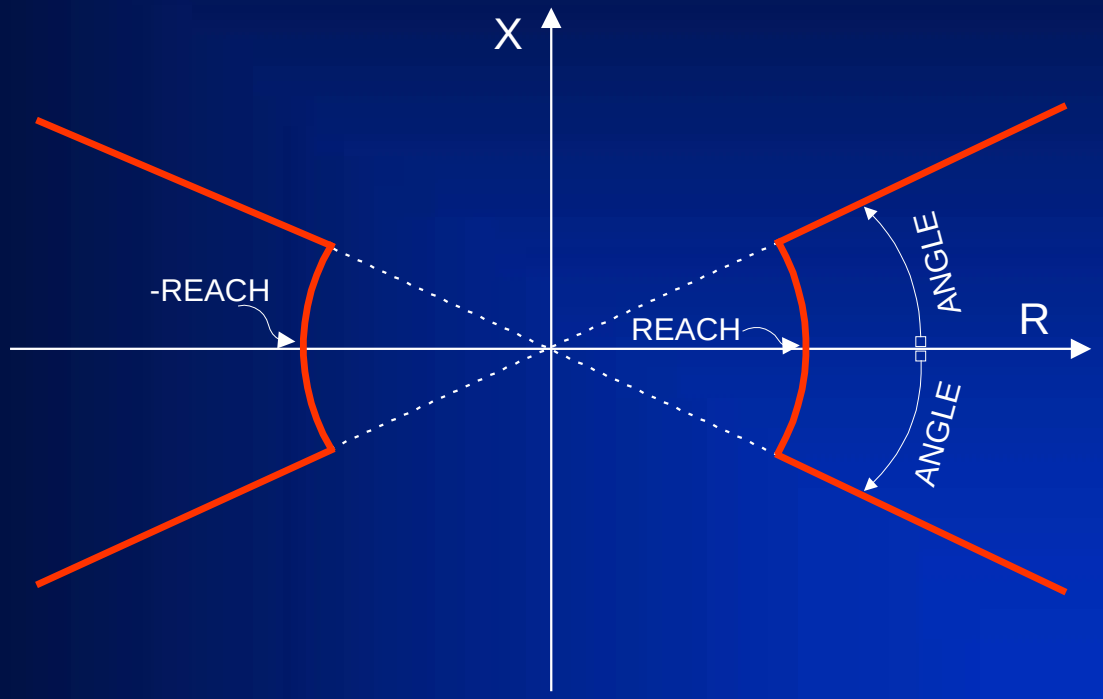
No load encroachment problems; directional integrity affected

Memory-polarized quad

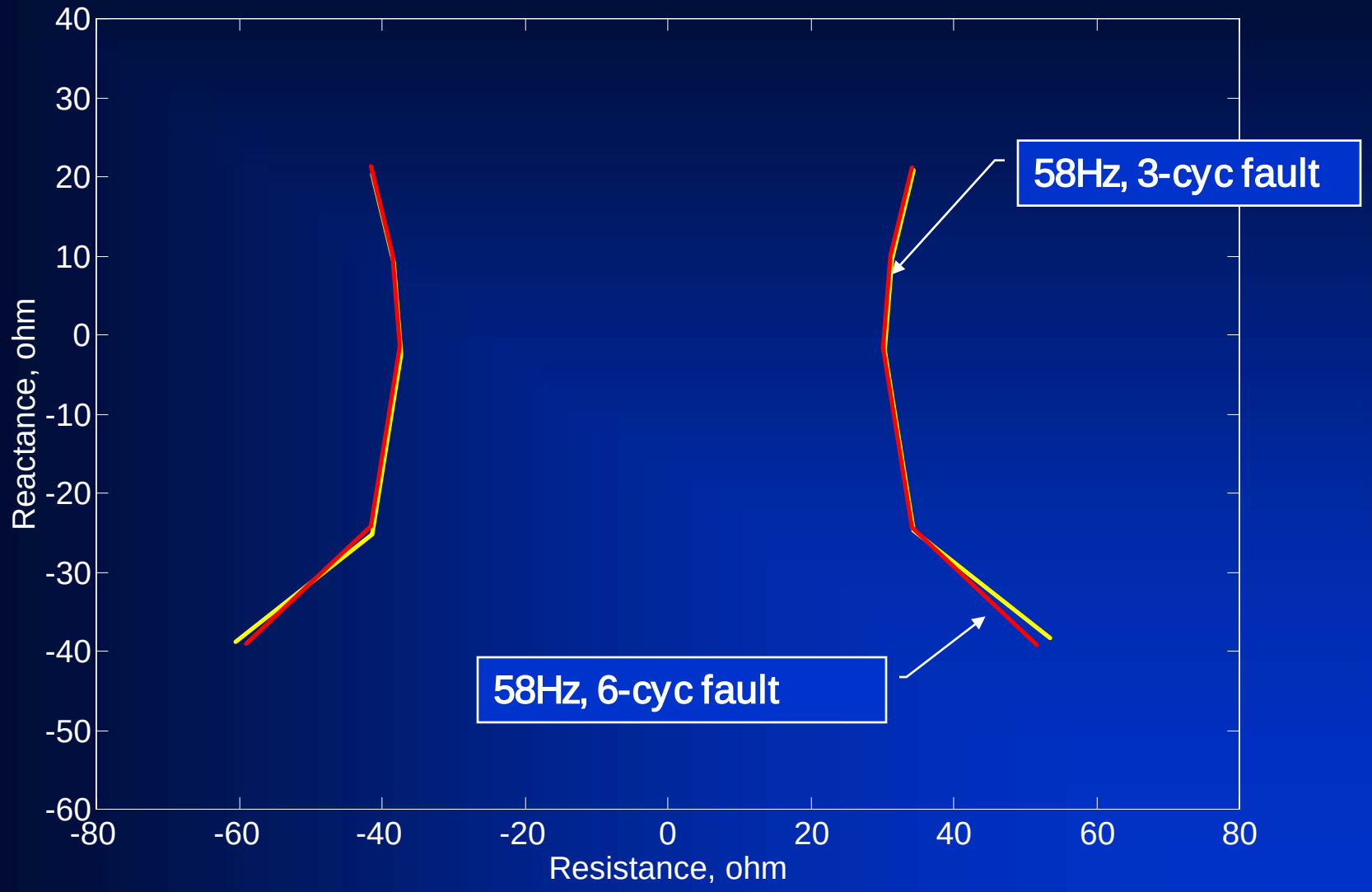


Only directional comparator is memory-polarized

Load Encroachment

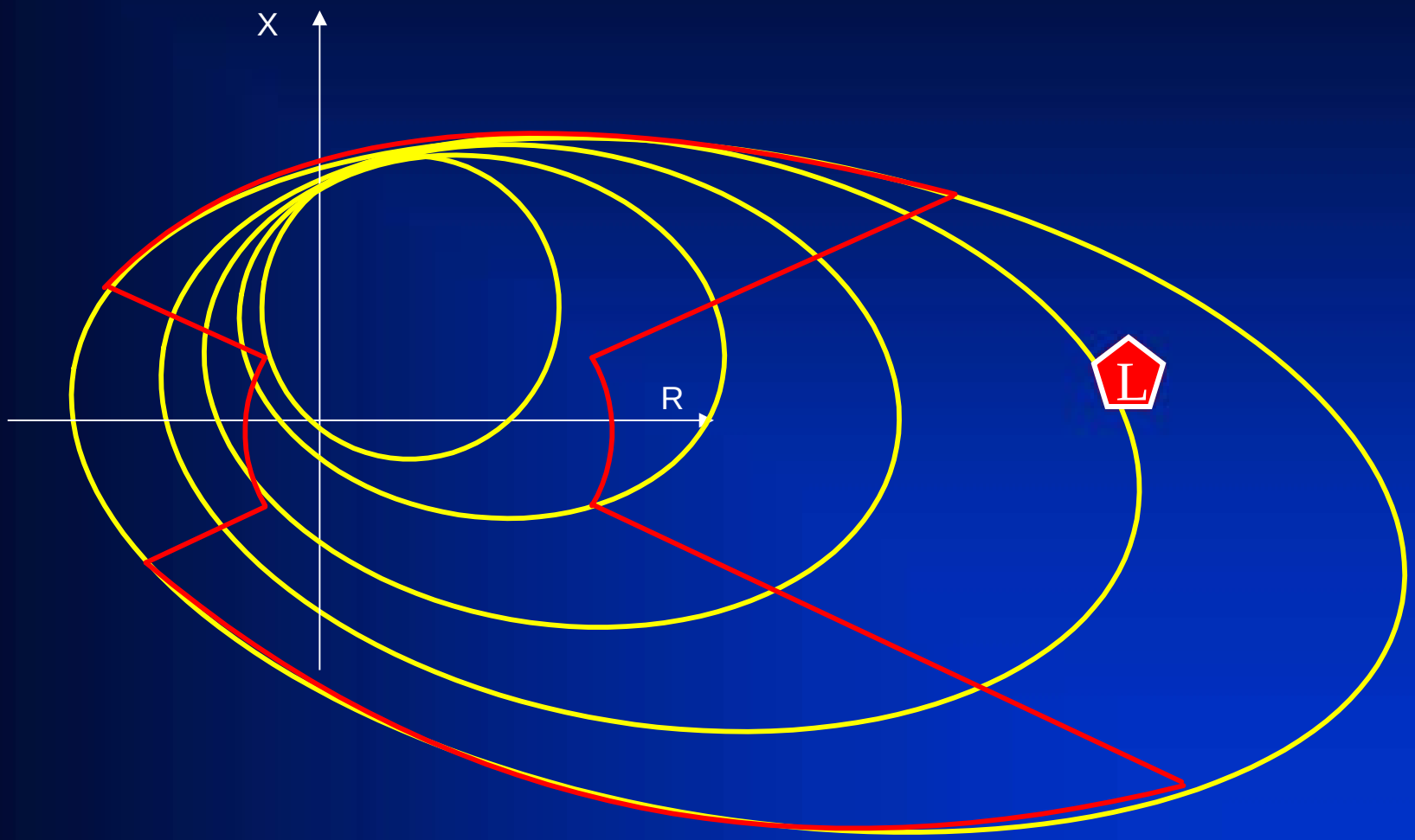


Load Encroachment (tracking off)



No problems, entirely static shape, slight accuracy degradation

Effect of Load Encroachment Supervision



Takeaways for Impedance Functions

- **Self-polarized comparators are only slightly affected:**
  - **Inspect memory duration settings; set just past the Breaker Failure time**
- **Memory polarization under relay-system frequency mismatch can be deadly:**
  - **Force – when possible - mho functions to self-polarized under abnormal frequency conditions**
  - **Use quad when possible**
  - **Apply load encroachment supervision**
- **Enable frequency tracking/compensation**

Testing for Impact of Frequency

- Examine and understand relay's frequency tracking/compensation design
- Check upper and lower tracking limits (e.g.3-75Hz)
- Test step change in frequency and estimate settling time of the tracking mechanism (e.g. 500ms)
- Test frequency ramp and estimate residual error in tracking (e.g. 0.1-10Hz/s)
- Test protection functions under assumed tracking error

Summary

- Simple functions affected marginally
- Enable frequency tracking/compensation on microprocessor-based relays
- Use static impedance characteristic under abnormal conditions (load encroachment, quad)
- Inquire with the manufacturer re impact of frequency
- When testing be careful with the method/script and results

Questions?