Characteristics of Line Tuner and Line Trap Failures in Carrier Relaying Channels

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Introduction

- Power Line Carrier – a type of pilot protection channel – provides a critical link between relays at either end of a transmission line

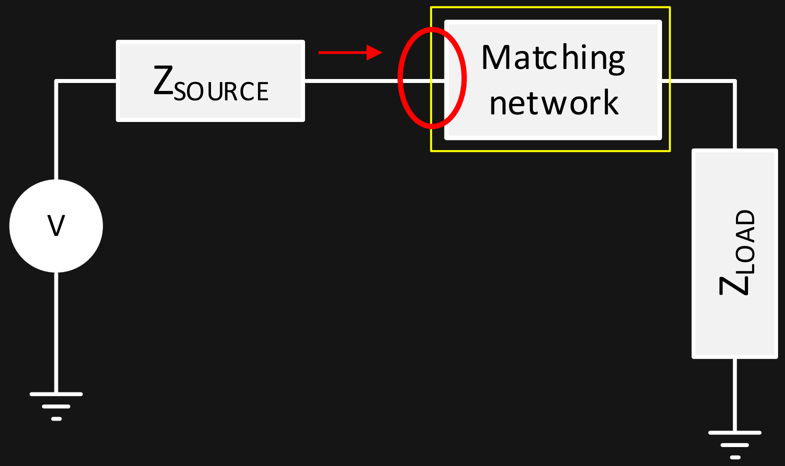
- Several devices work together to "match" carrier circuits to the transmission line, and to isolate the matched circuit from external influences

- "Reflected Power" has been used since around 2000 as a way for transmitters to monitor the quality of the "matching"

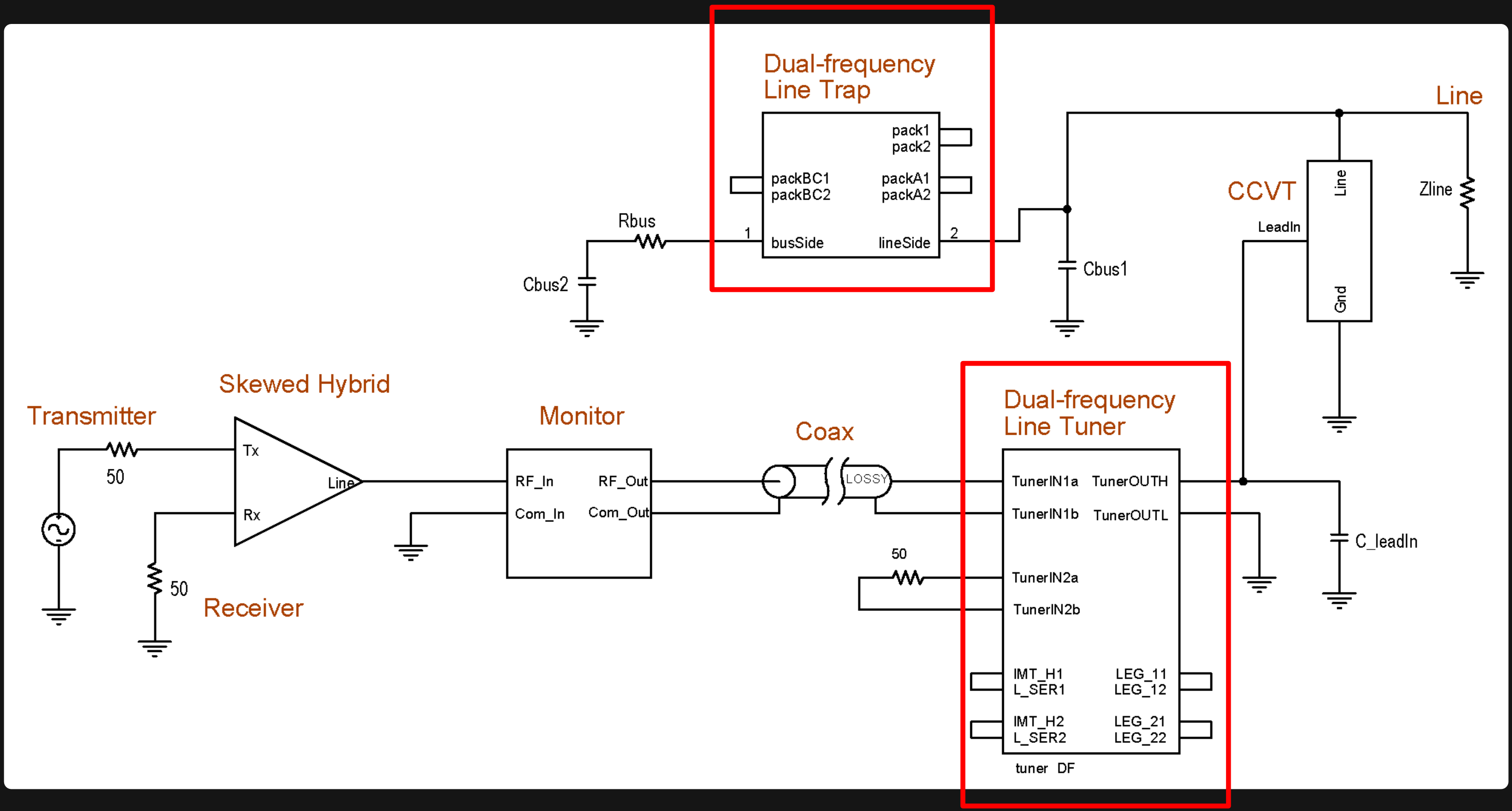
Why Match?

- Maximum power transfer theorem states that when the *load impedance* is equal to the *complex conjugate* of the *source impedance*:
  - Maximum power is transferred to the load
  - Minimum power is reflected from the load back to the source

$$R_{SOURCE} + jX_{SOURCE} = R_{LOAD} - jX_{LOAD}$$

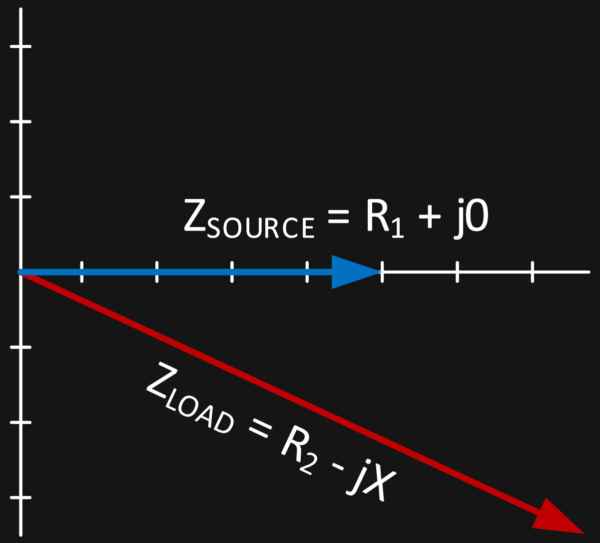


Carrier Terminal Overview



Typical Carrier Impedances

- The nominal equipment-side impedance for carrier terminals in the US is 50 ohms at 0 degrees
- The real component of the line-side impedance is typically in the range of 200-600 ohms
- The reactive component of the line-side impedance is typically capacitive



Impedance vs Reflected Power

- Using voltage *and current* measurements, monitoring devices provide data about the complex impedance at the line tuner input (Z_{TERM})

$$Z_{SOURCE} = 50 + j0$$

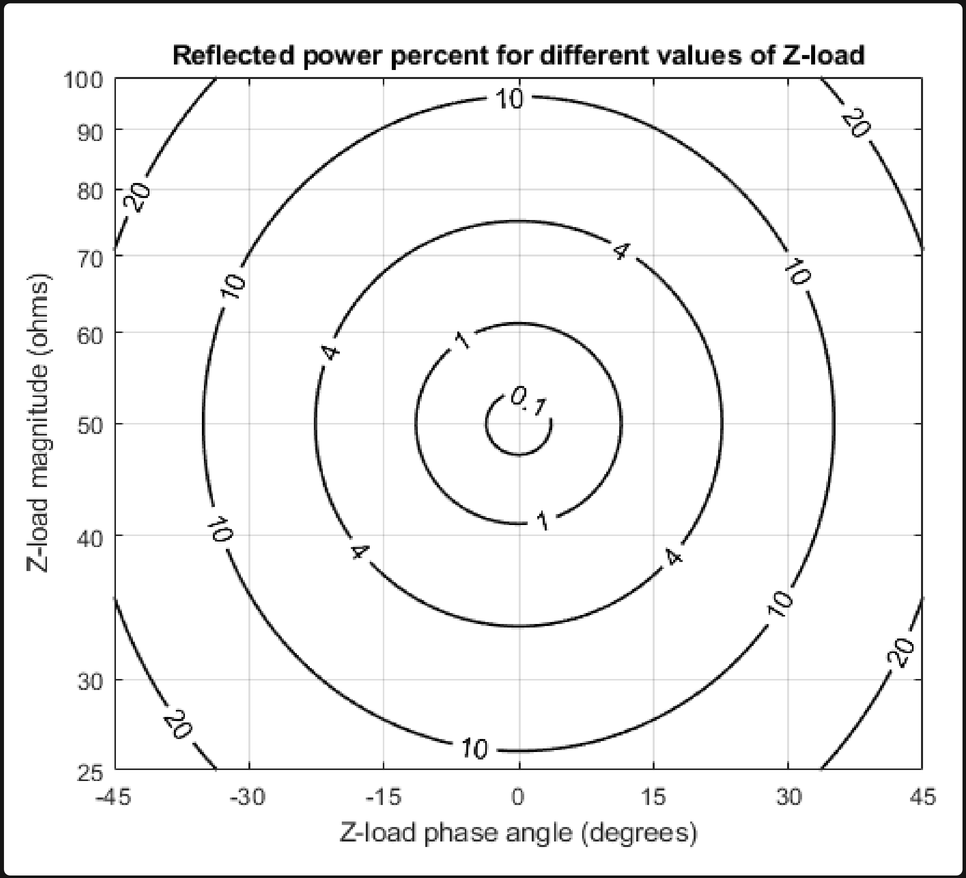
$$Z_{TERM} = RL + jX_L$$

$$\rho = \frac{Z_{TERM} - ZSO_{URCE}}{Z_{TERM} + Z_{SOURCE}}$$

$$RP\% = 100 * |\rho|^2$$

- A contour map would be helpful here…

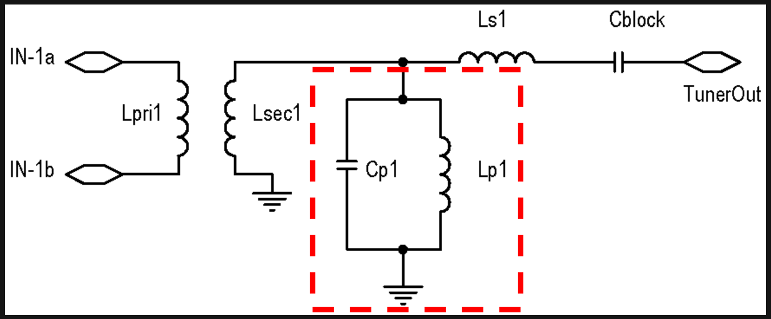
Impedance vs Reflected Power



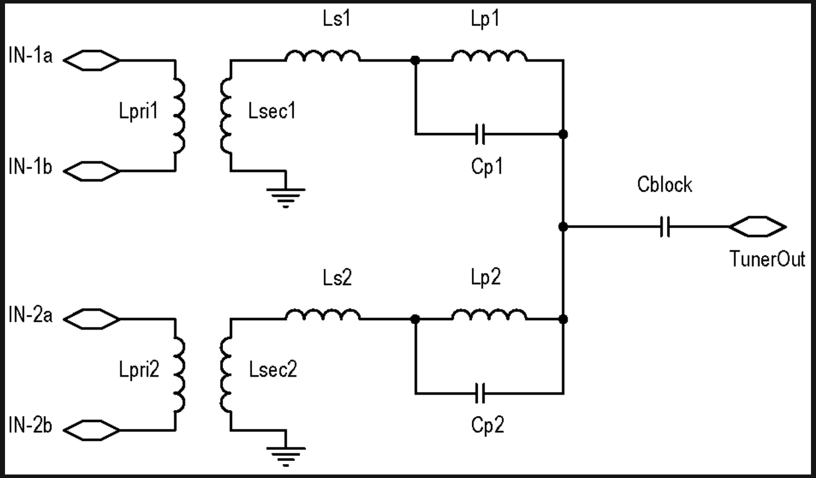
Contour map of reflected power % versus Z_{LOAD} (for Z_{SOURCE} = 50 Ω, 0°)

Line Tuners

Single Frequency Wideband

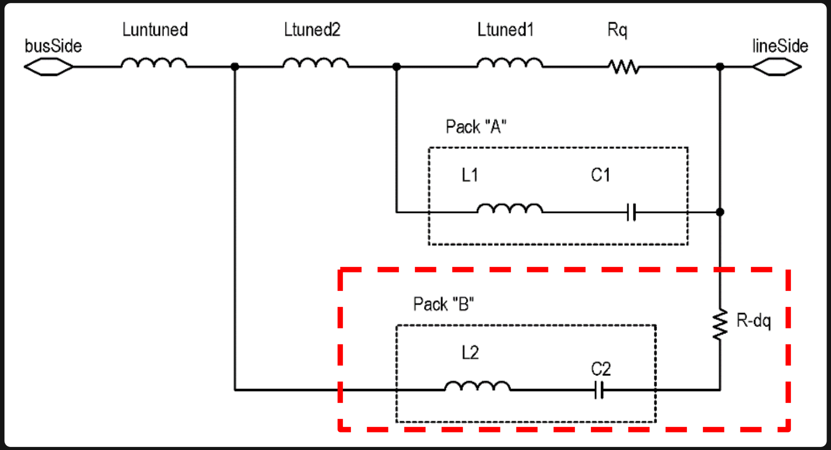


Dual-frequency

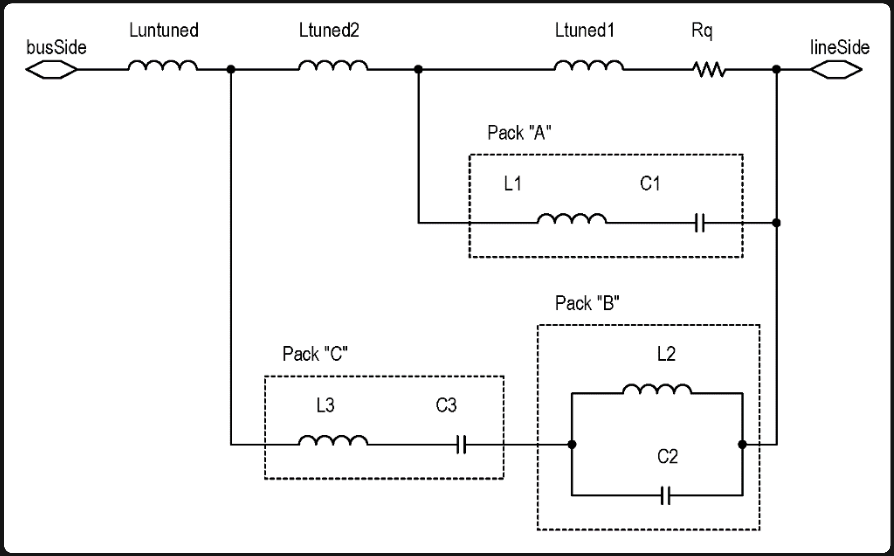


Line Traps

Single Frequency Wideband



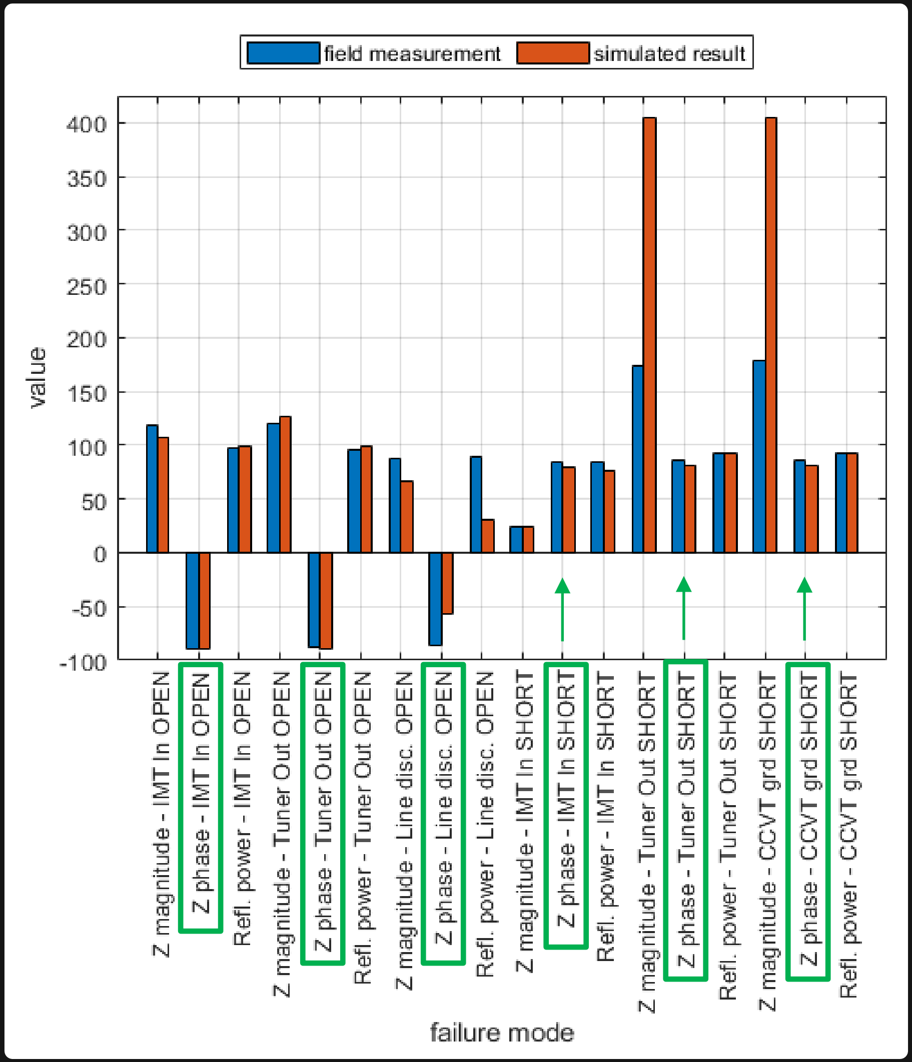
Dual-frequency



Monitoring Impedance Matching

- Line tuner input is the primary location to monitor the impedance matching of the carrier system
- Frequency-selective voltage and current measurements enable the measurement of complex impedance at the tuner input
- Changes to the tuner input impedance contain the “signature” of failures in the system
- Simulations were run with comparison to field data to look for easily recognizable signatures

Field Tests vs Simulation



Tests Run

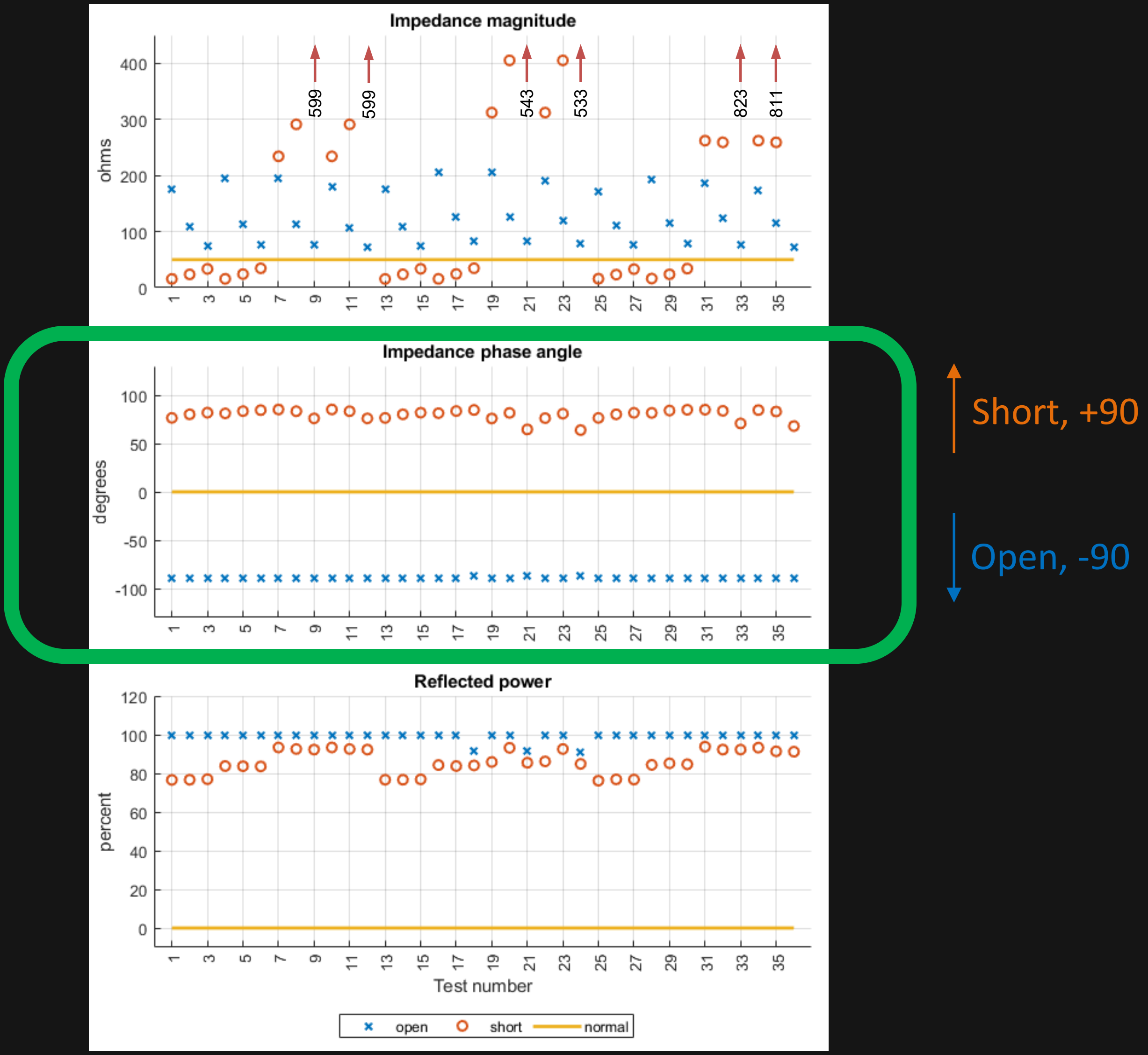
Line Tuners

Failure (Open or Short)	Frequency and Line Tuner Type								
	Single Freq.			Wideband			Dual Freq.		
	100 kHz	150 kHz	200 kHz	100 kHz	150 kHz	200 kHz	100 kHz	150 kHz	200 kHz
IMT in	1	2	3	13	14	15	25	26	27
Ls out	4	5	6	16	17	18	28	29	30
Line	7	8	9	19	20	21	31	32	33
CCVT	10	11	12	22	23	24	34	35	36

Line Traps

Failure (Open)	Frequency and Line Trap Type								
	100 kHz			150 kHz			200 kHz		
	Single Freq.	Wideband	Dual Freq.	Single Freq.	Wideband	Dual freq.	Single Freq.	Wideband	Dual freq.
All packs	1	2	3	4	5	6	13	14	15
Pack A only	-	-	-	7	8	9	16	17	18
Pack B / Pack BC	-	-	-	10	11	12	19	20	21

Line Tuner Results

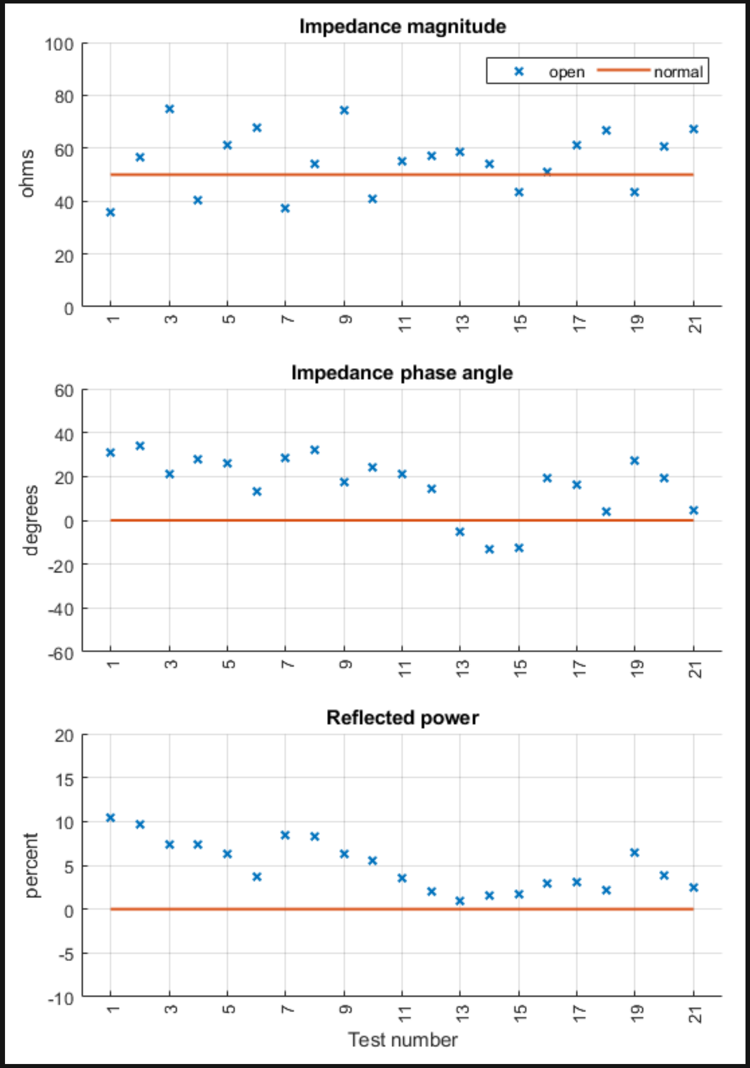


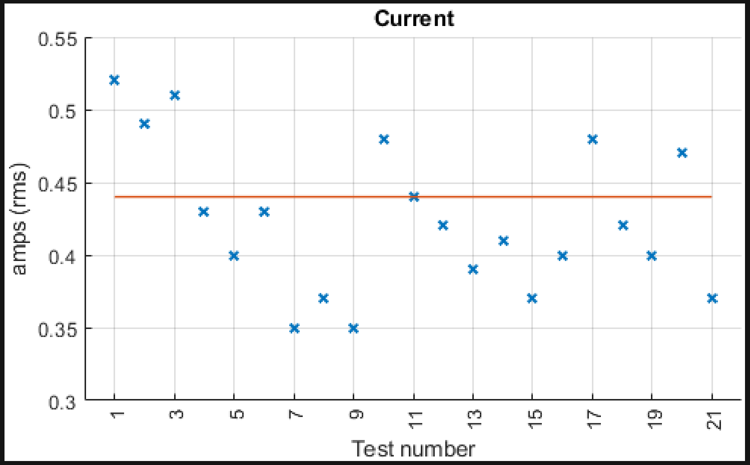
Line Tuner Results

- Impedance magnitude is not a reliable indicator of failure state
  - Counterintuitively, it actually *increases* for some short-circuit failures (on the line-side of the tuner)
- Reflected power clearly indicates a failure, but very hard to distinguish between an open and a short
  - Increases markedly but in the same direction – towards 100%

- Phase angle clearly indicates the failure as well as the type
  - ***Towards +90 for short circuit***
  - ***Towards -90 for open circuit***

Line Trap Results





Line Trap Results

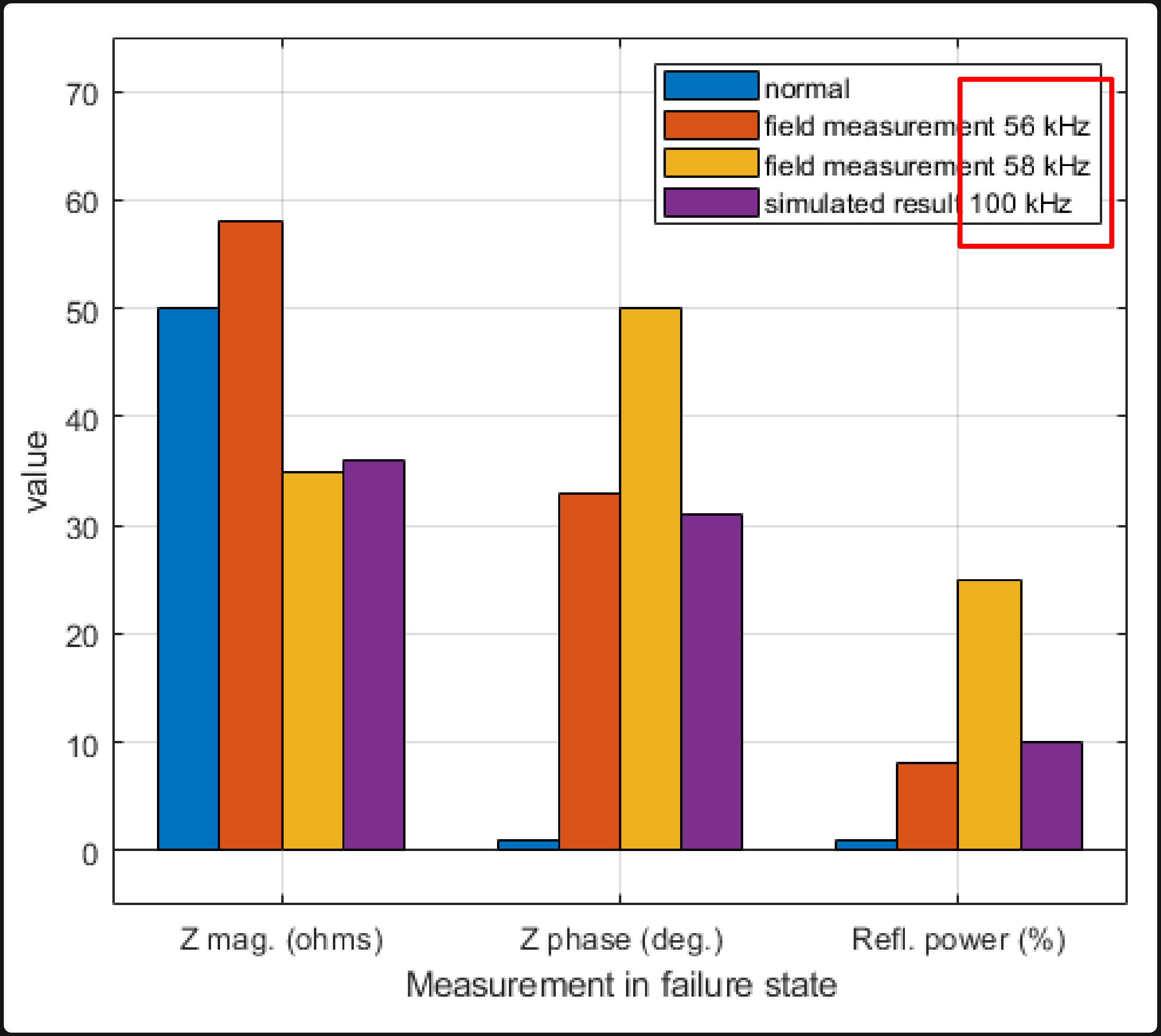
- Significantly less severe changes in tuner input impedance for line trap failures
  - To be expected – these don't *open* or *short* the coupling circuit

- Transmitter current does *not* increase for all failure conditions
  - Current into the bus increases, current into the line decreases
  - However, not necessarily the current out of the transmitter

- Positive phase angle may indicate trap failure, however, there are exceptions (dual-frequency)

- Field results corroborate the simulations

Line Trap Results – Field vs Simulation



Applying the Insights

- Tuner failures (open and short) are easy to simulate in the field, at maintenance intervals or commissioning
  - Ideally with the carrier channel in the “known good” state

- Exact impedance values for different failures at the site are recorded and can be referenced later, if the failure occurs in an operational context
  - Knowing that the failure is either an open or short can considerably simplify troubleshooting and investigation

- Trap failures are harder to simulate in the field

Conclusions

- Phase angle is a good indicator of a “short” versus “open” failure in the carrier matching circuit
- The same cannot be said for line trap failures, which cause less significant changes to the tuner input impedance
- Exact values of the complex impedance at the tuner input will vary from site to site, but the characteristics will be similar
- Test or monitoring equipment which can record simulated failure states at commissioning will provide a reference if/when an operational failure occurs

Questions & Discussion