Jeff Welton

Sales Manager, Central USA

Nautel

Stephen Lockwood

President/Senior Electrical Engineer

Hatfield & Dawson Consulting Engineers

TRANSMISSION TALK TUESDAY

Episode #79

Smith Charts, MER and More

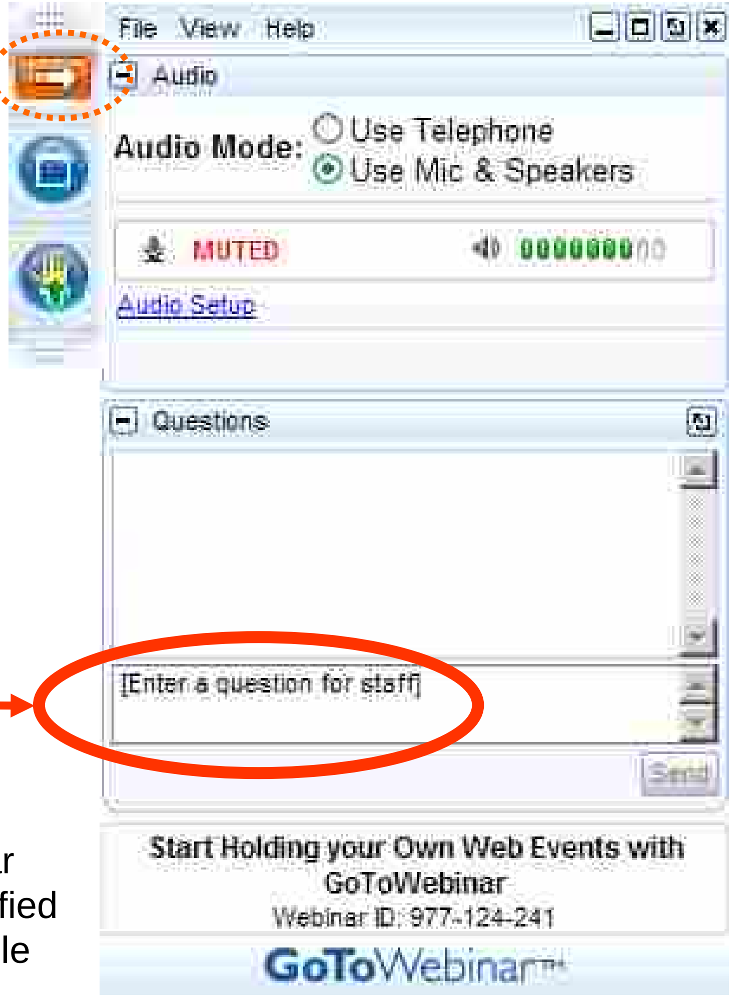
nautel

AM/FM Radio Transmitters

Your questions please?

(if you don’t see the control panel, click on the orange arrow icon to expand it)

Please enter your questions in the text box of the webinar control panel (remember to press send)

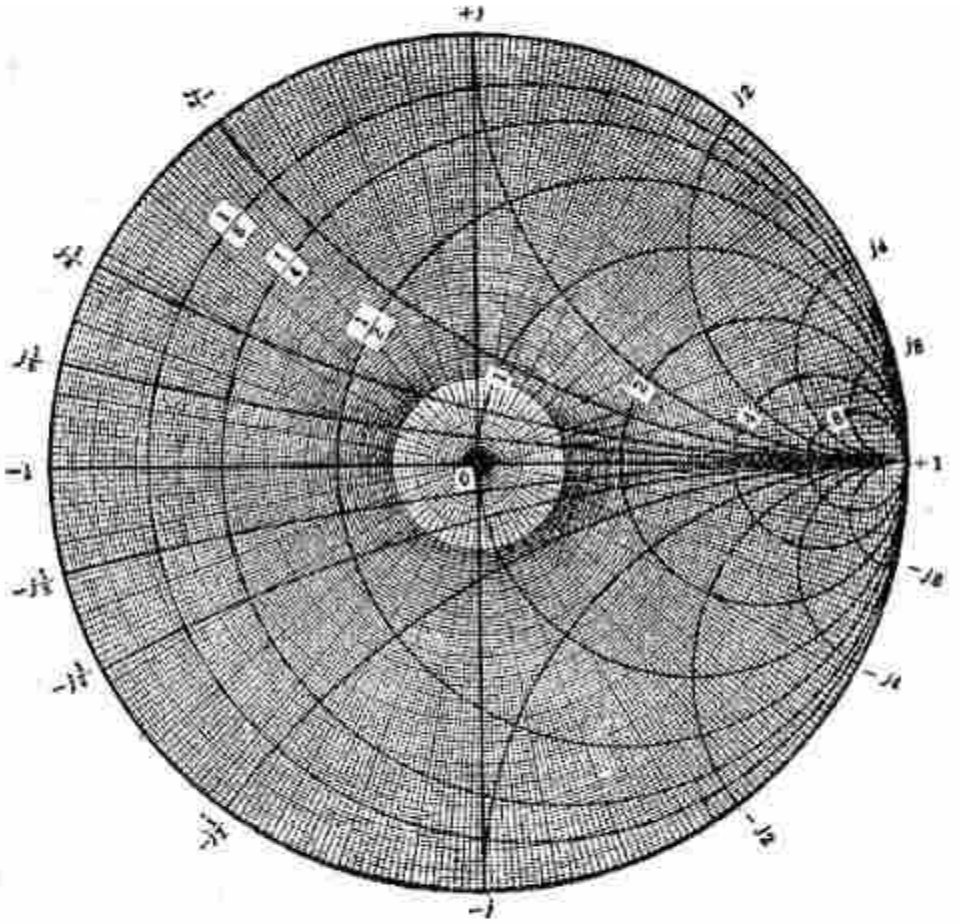


Remember: The completion of a Nautel webinar qualifies for ½ SBE re-certification credit, identified under Category I of the Re-certification Schedule for SBE Certifications.

Who was Philip H. Smith

- Born 1905 – BSEE from Tufts College
- Bell Labs Engineer & IRE (IEEE from 1947) Fellow
- Worked on AM directional antennas and shortwave antennas
- Worked in transmission line and impedance matching
- Needed a graphical calculator for these purposes
- Published method in mid-1930s
- WWII worked with the MIT Radiation Labs, where his chart was used extensively
- Published book in 1969
- Not to be confused with Carl E. Smith – Consulting Engineer & Educator

Who was Mizuhashi Tosaku?



第一圖　反射係數 γ の Z_{01} (及 Z_{02}) に對する圓線圖

- Engineer with Japan Wireless Telegraph

  Published a paper in 1937 including a tool for graphically calculating impedance.

The Smith chart

- Graphic calculator for when math costs a lot
- Convenient, simple graphical methods to depict complex impedance
- Show impedance over the bandwidth of interest
- For transmitters to provide the most power and performance, the load must be matched to the transmitter.   Mostly 50 Ohm systems

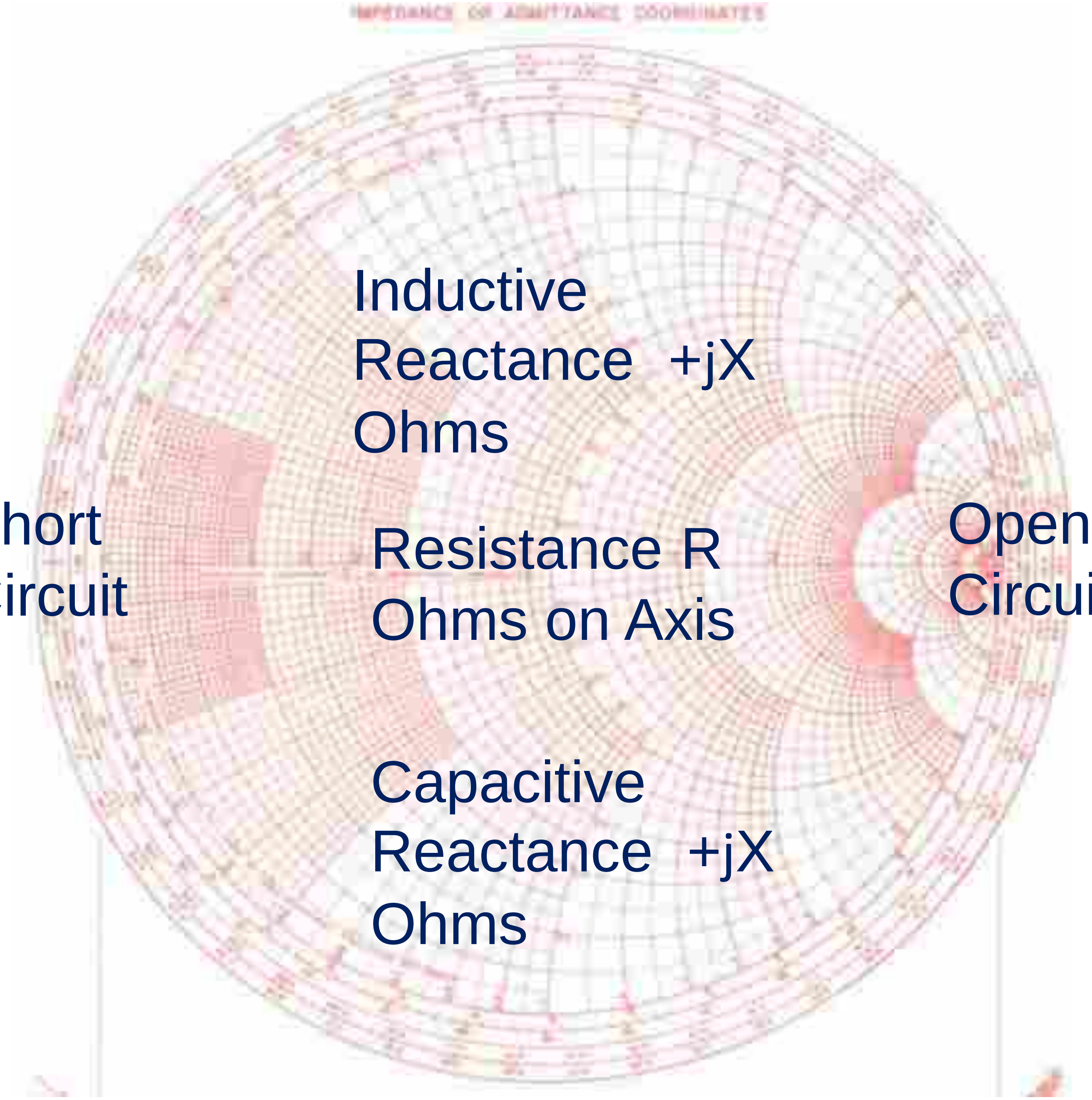
Test equipment

- Network Analyzers can measure complex impedance
- Three methods to display
  - Smith Chart – Antenna Engineer Talk
  - VSWR – Transmitter Engineer Talk
  - Return Loss – Two-Way, Microwave Engineer Talk

Smith Chart (Impedance)	VSWR	Return Loss
50 ± j 0	1.0:1	< -60 dB
45 -j 5	1.16:1	-22.6 dB
40 -j 10	1.37:1	-16.1 dB

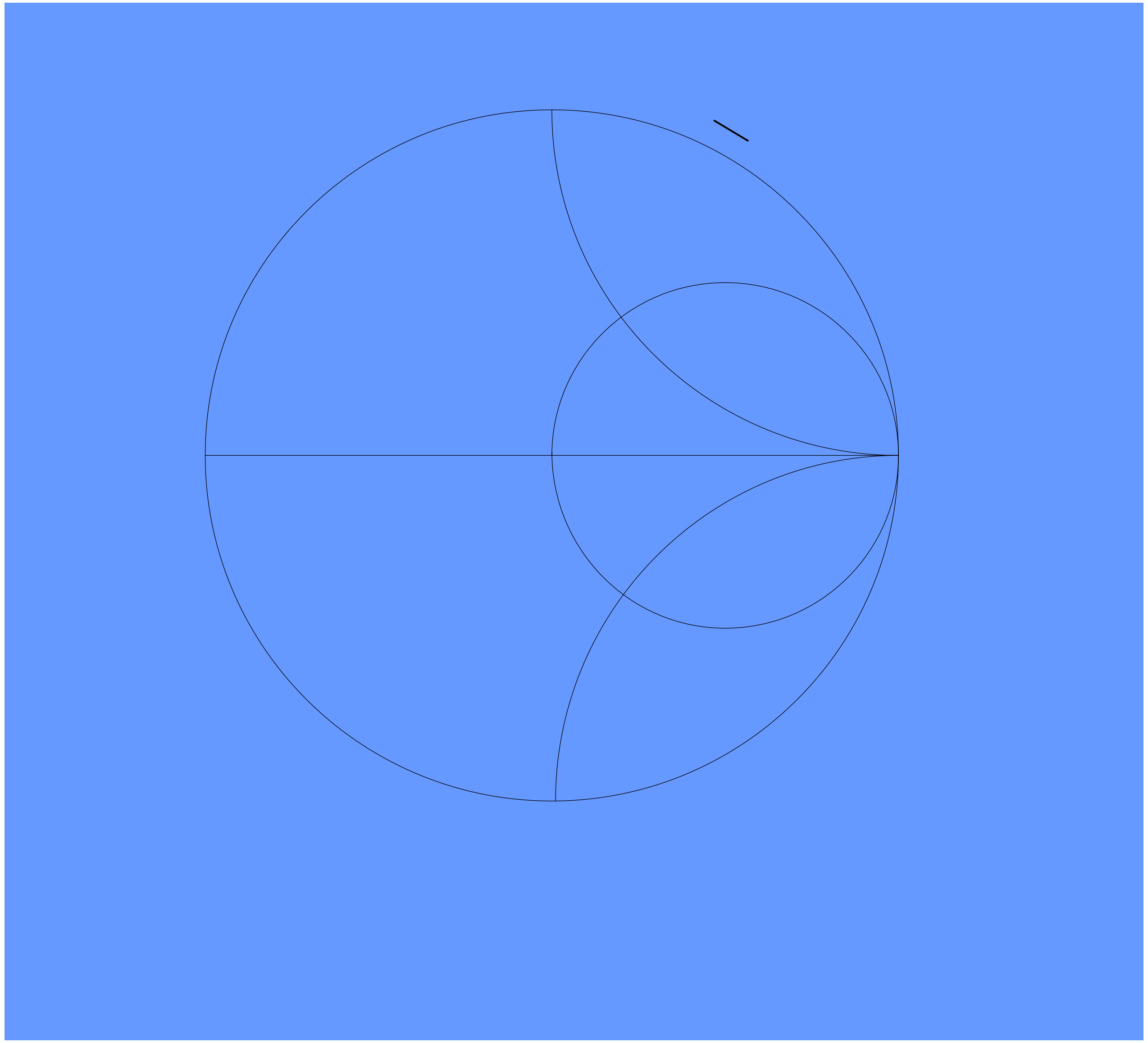
Resistance and reactance review

- Resistance is measured in Ohms
- Capacitive Reactance
  - In Ohms $-jX_C = \frac{1}{2\pi f C}$ Where f is the frequency in Hz and C is capacitance in farads
- Inductive Reactance
  - In Ohms $+jX_L = 2\pi f L$ Where f is the frequency in Hz and L is inductance in Henries
- This gives us a complex impedance of R ± jX Ohms
- Complex math is hard and takes time - graphical ways to do complex math were very valuable



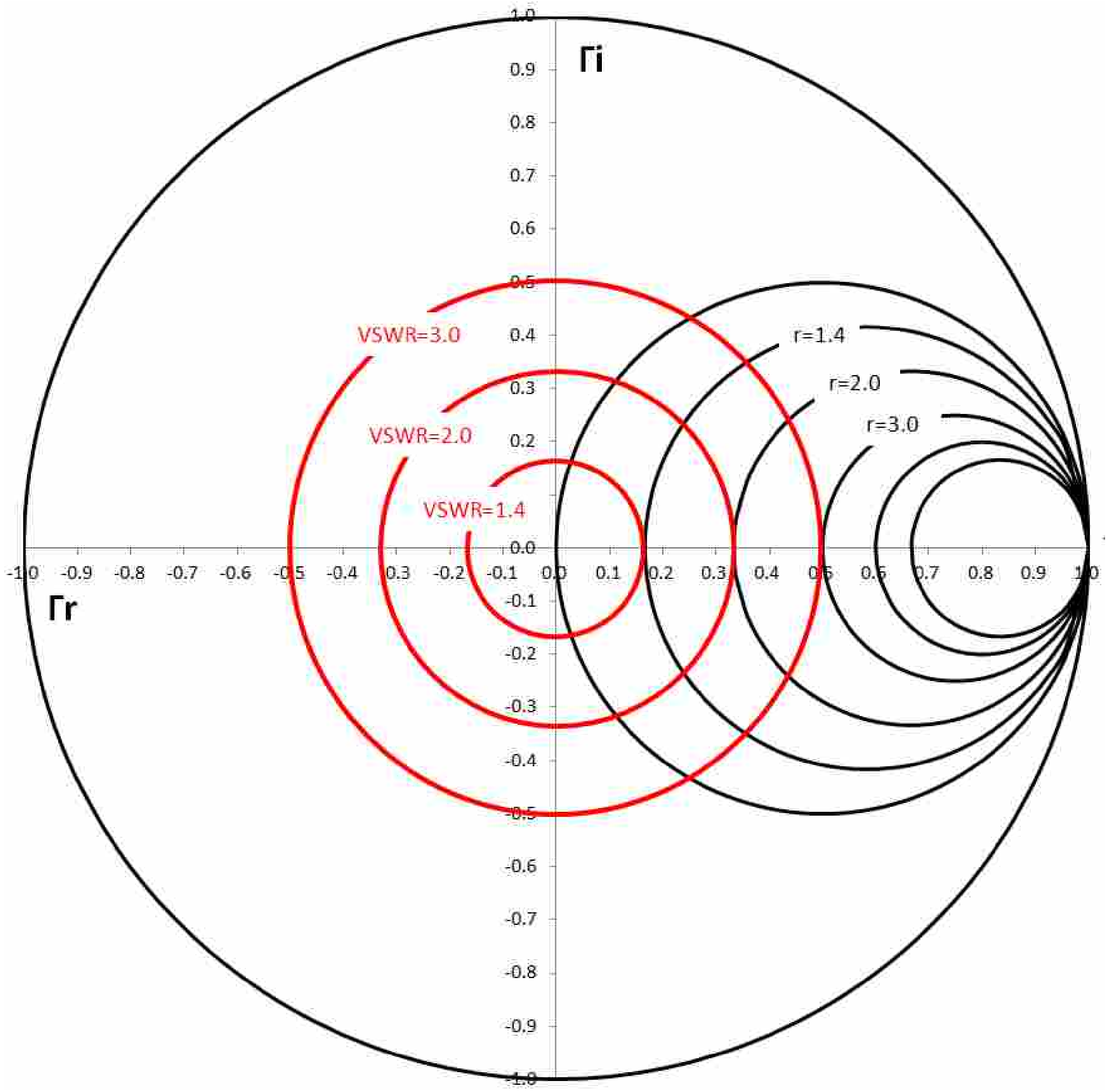
Smith Charts are normalized for the operating impedance of the transmission system Z_0 = 50 Ohms.

The center of the chart for our application is 50 ±j 0 Ohms.



For transmission line application, one revolution of the chart is 180°, ½ λ, or one-half wavelength.

Clockwise rotation is toward the generator.



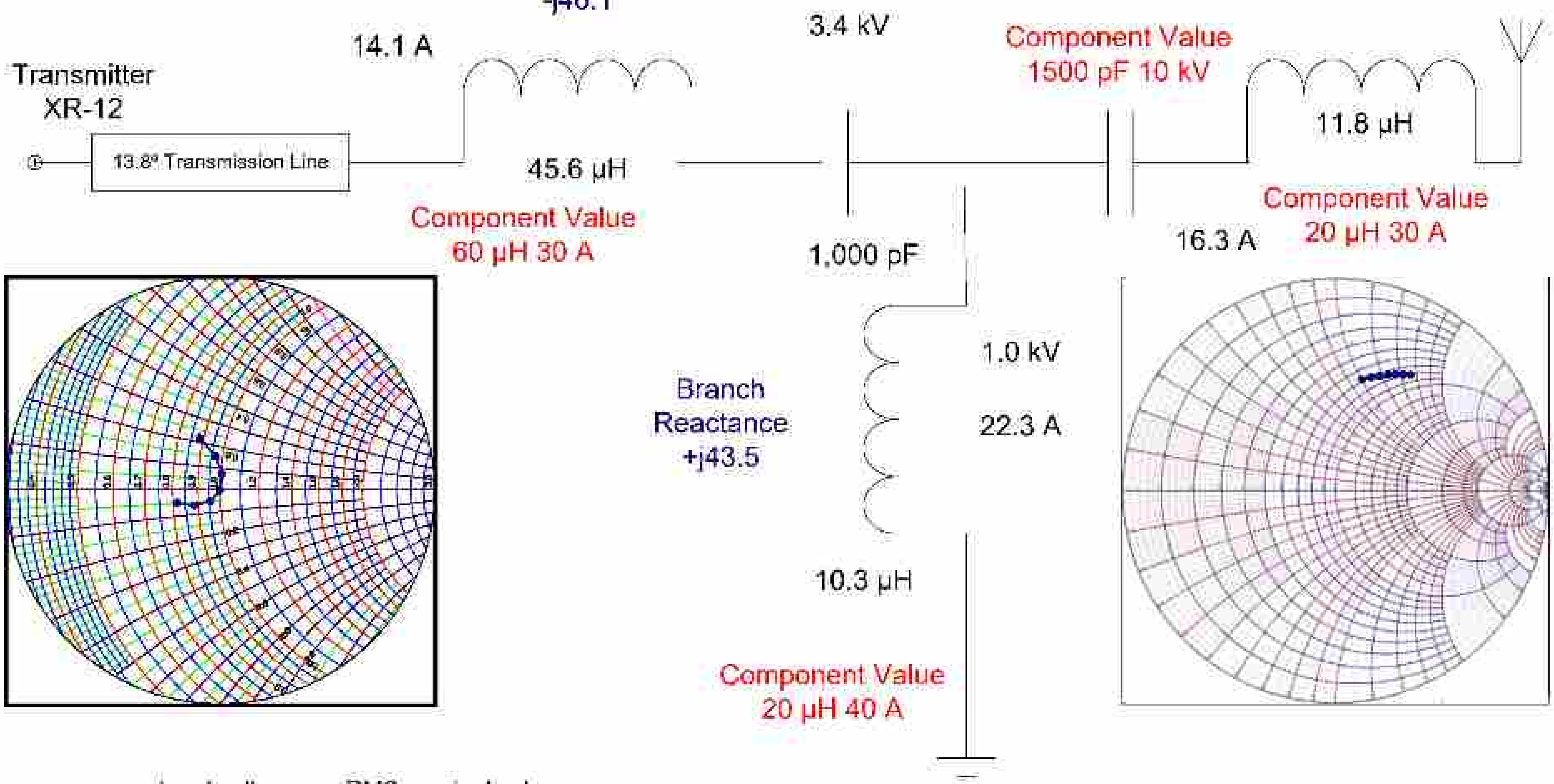
VSWR can be plotted as circles around the 50 ±j 0 Ohms origin

Γr & Γi are reflection coefficients

This chart is shown in the reflection coefficient plot.

Frequency	Impedance		
(kHz)	Resistance	Reactance	VSWR
656	44.3	11.0	1.299
660	48.5	7.7	1.173
665	50.3	3.8	1.079
670	50.0	0.0	1.000
675	47.7	-2.4	1.070
680	44.4	-3.2	1.146
685	40.9	-2.4	1.232

KDLG	Measured	
Freq (kHz)	R	X
655.0	34.8	50.5
660.0	35.8	54.8
665.0	36.8	59.0
670.0	37.7	63.4
675.0	38.8	67.7
680.0	40.0	72.1
685.0	41.2	76.5

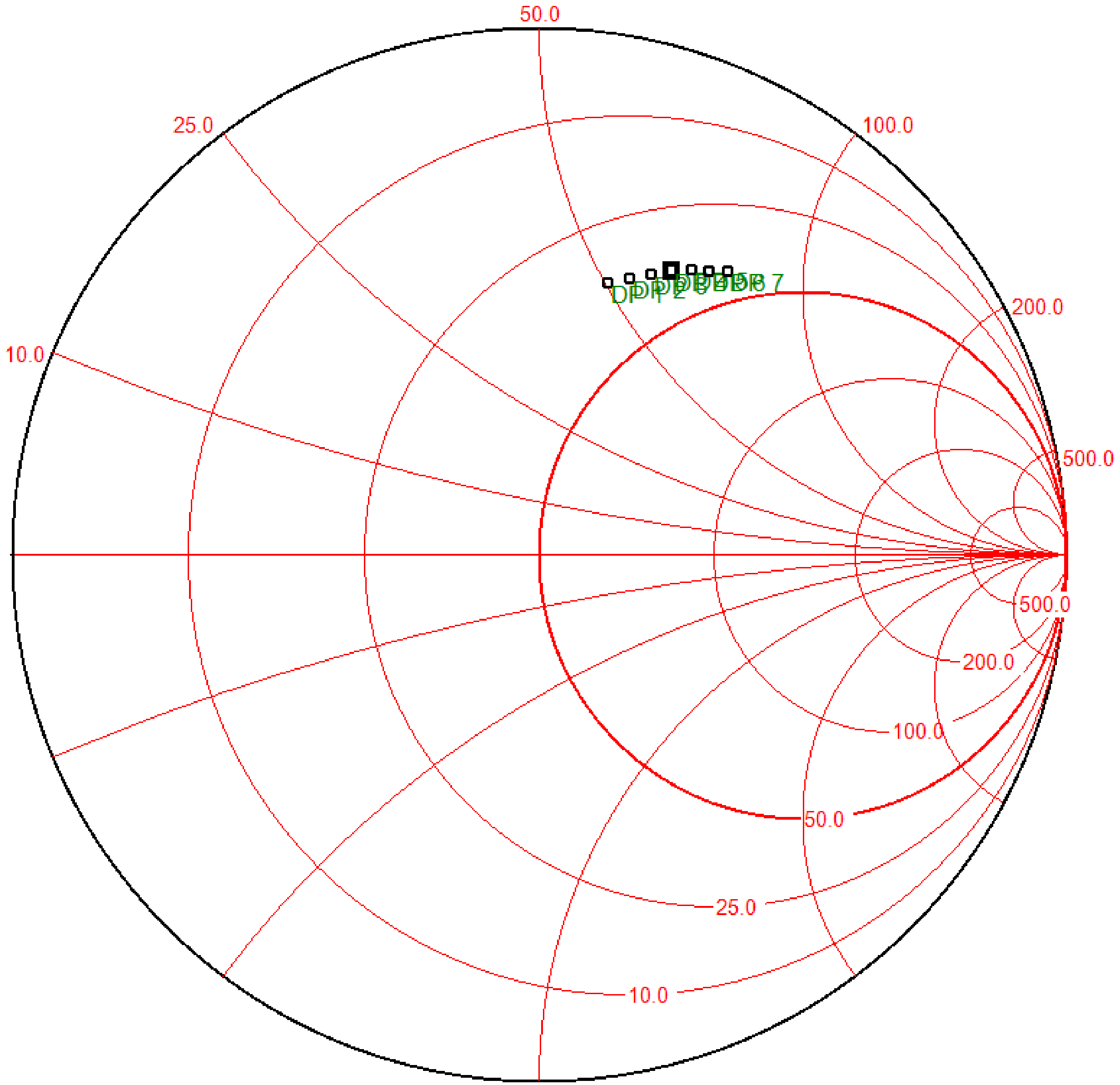


current and voltage are RMS nominal values
use safety factors of 1.7 for current and 3.5 for voltage

IBOC Phase Rotation and Bandwidth Correction
KDLG, 670 kHz, 10 kW Dillingham, AK

Smith chart video game (best I have found)

- https://www.fritz.dellsperger.net/smith.html
- Published by Professor Fritz Dellsperger (Herr Doktor) Bern University Switzerland
- Lots of Amazing Mathcad, Matlab, and other computational tools available

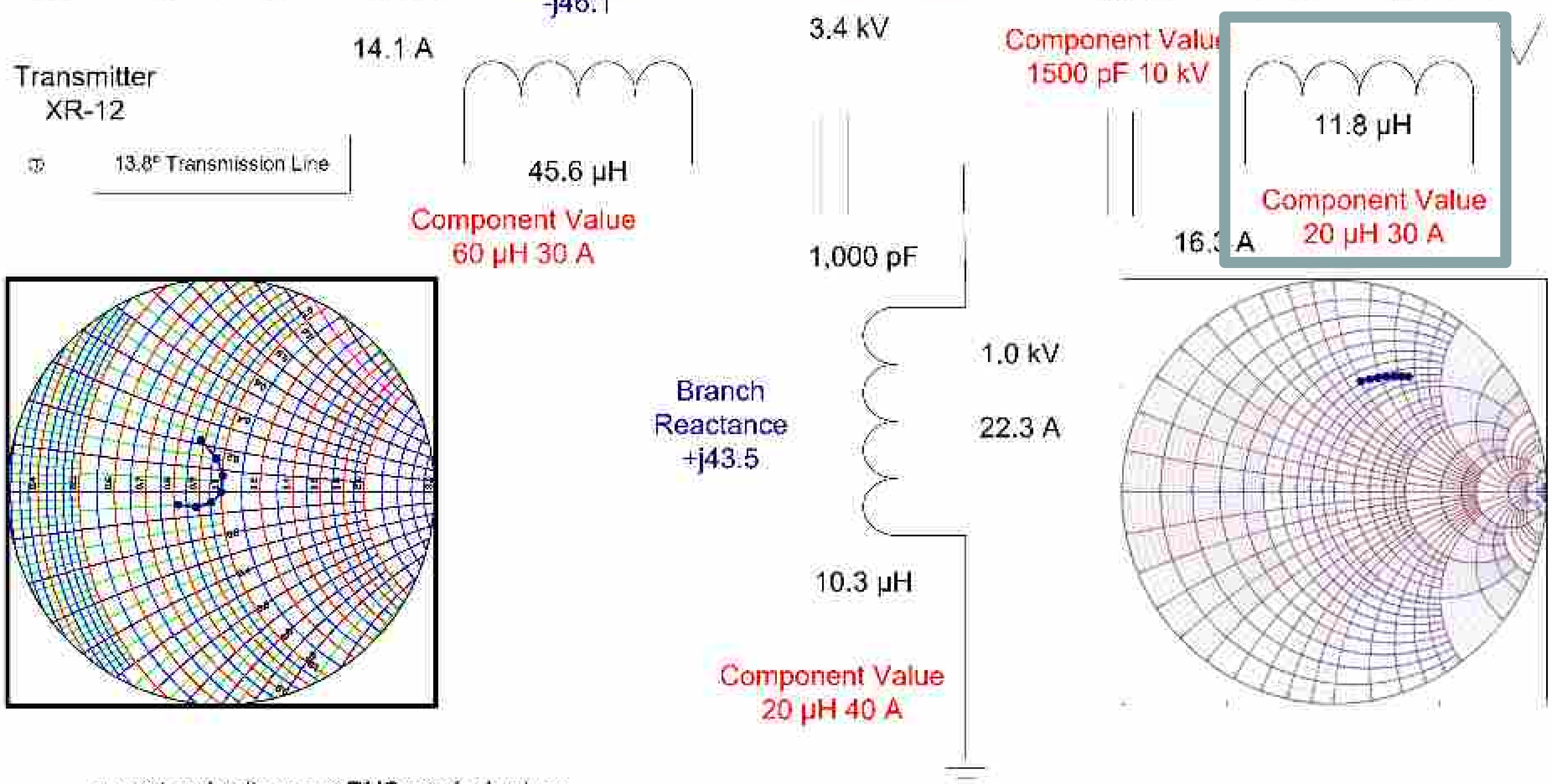


Datapoints

Start DP	Point	Z	Q	Frequency
☐	DP 1	(34.800 + j50.500) Ω	Q=1.451	655.000kHz
☐	DP 2	(35.800 + j54.800) Ω	Q=1.531	660.000kHz
☐	DP 3	(36.800 + j59.000) Ω	Q=1.603	665.000kHz
☑	DP 4	(37.700 + j63.400) Ω	Q=1.682	670.000kHz
☐	DP 5	(38.800 + j67.700) Ω	Q=1.745	675.000kHz
☐	DP 6	(40.000 + j72.100) Ω	Q=1.803	680.000kHz
☐	DP 7	(41.200 + j76.500) Ω	Q=1.857	685.000kHz

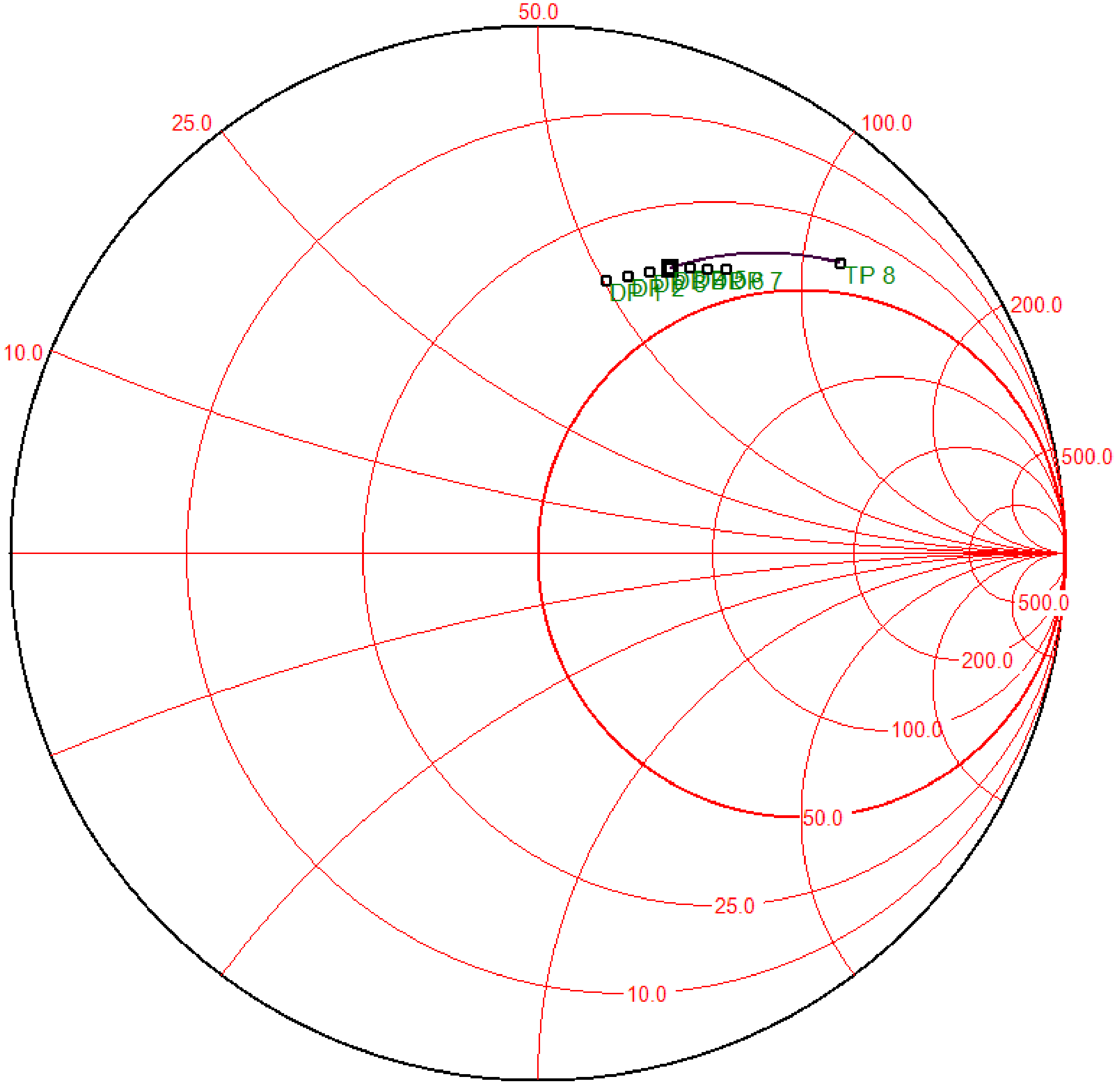
Frequency (kHz)	Impedance Resistance	Reactance	VSWR
655	44.3	11.0	1.299
660	48.5	7.7	1.173
665	50.3	3.8	1.079
670	50.0	0.0	1.000
675	47.7	-2.4	1.070
680	44.4	-3.2	1.146
685	40.9	-2.4	1.232

KDLG Freq (kHz)	Measured R	X
655.0	34.8	50.5
660.0	35.8	54.8
665.0	36.8	59.0
670.0	37.7	63.4
675.0	38.8	67.7
680.0	40.0	72.1
685.0	41.2	76.5



current and voltage are RMS nominal values
use safety factors of 1.7 for current and 3.5 for voltage

IBOC Phase Rotation and
Bandwidth Correction
KDLG, 670 kHz, 10 kW Dillingham, AK

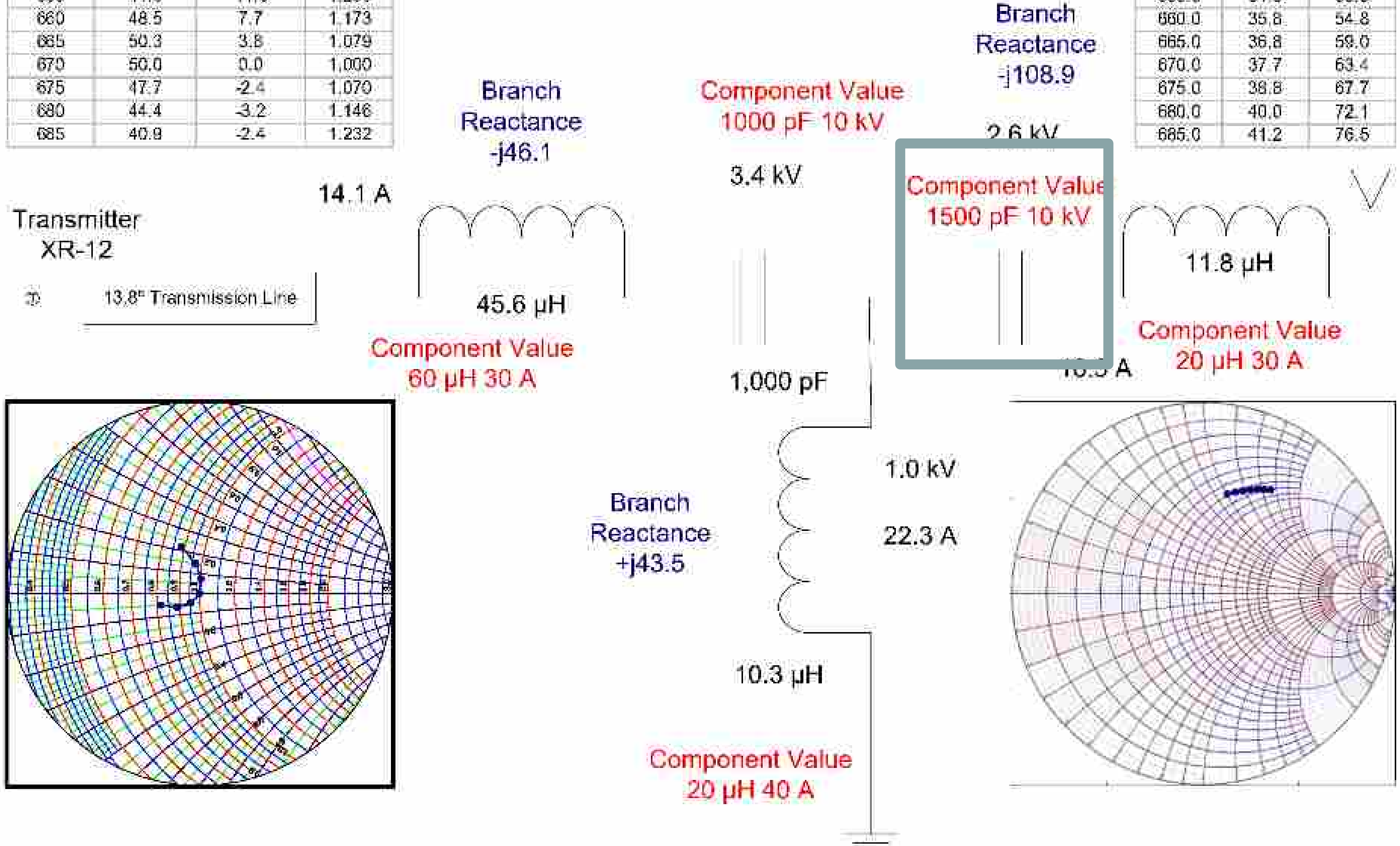


Add series 11.8 µH inductor

Moves us to 37.7 + j 113.3 Ohms

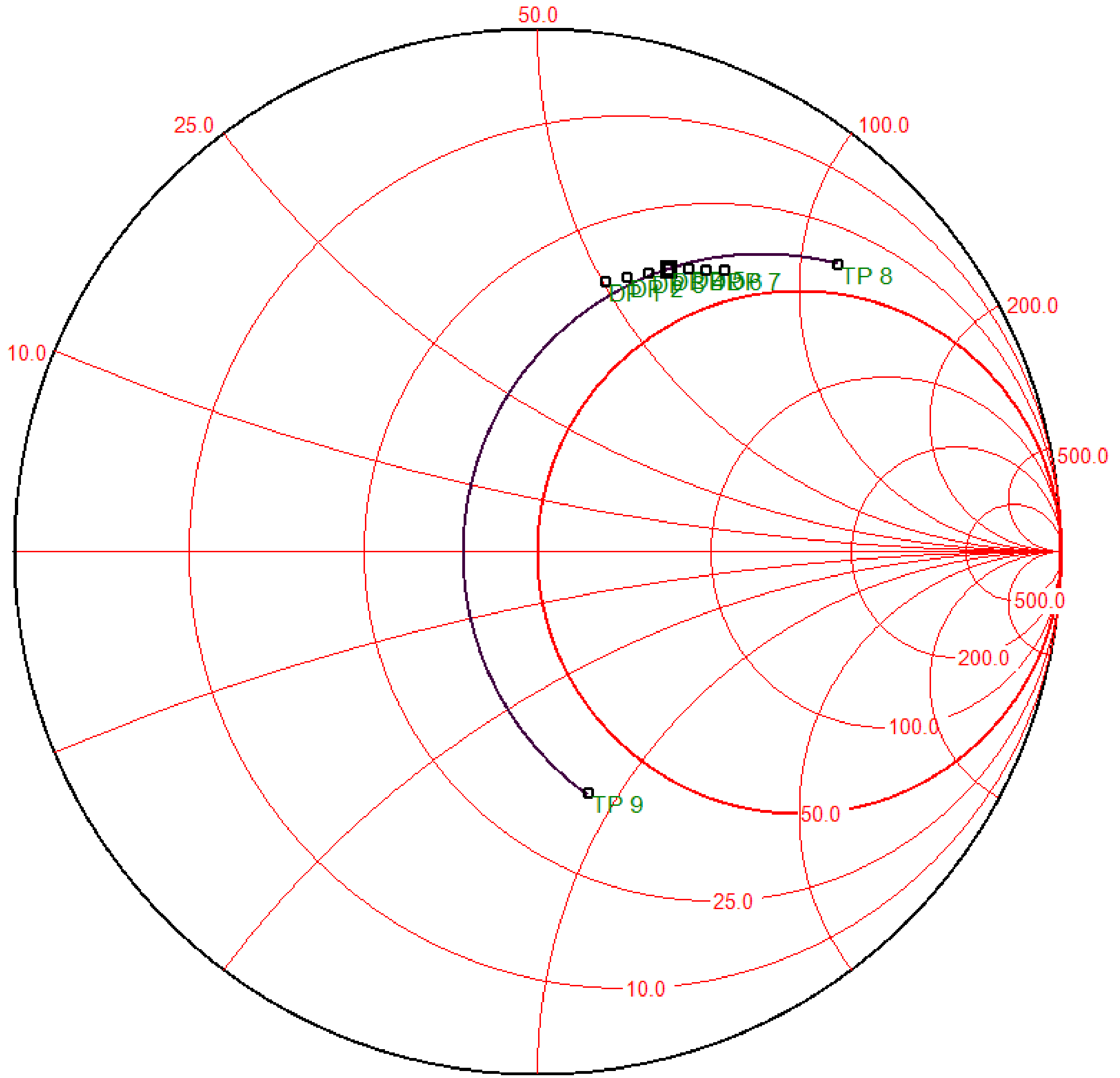
Frequency	Impedance		
(kHz)	Resistance	Reactance	VSWR
655	44.3	11.0	1.299
660	48.5	7.7	1.173
665	50.3	3.8	1.079
670	50.0	0.0	1.000
675	47.7	-2.4	1.070
680	44.4	-3.2	1.146
685	40.9	-2.4	1.232

KDLG	Measured	
Freq (kHz)	R	X
655.0	34.8	50.5
660.0	35.8	54.8
665.0	36.8	59.0
670.0	37.7	63.4
675.0	38.8	67.7
680.0	40.0	72.1
685.0	41.2	76.5



current and voltage are RMS nominal values
use safety factors of 1.7 for current and 3.5 for voltage

IBOC Phase Rotation and Bandwidth Correction
KDLG, 670 kHz, 10 kW Dillingham, AK

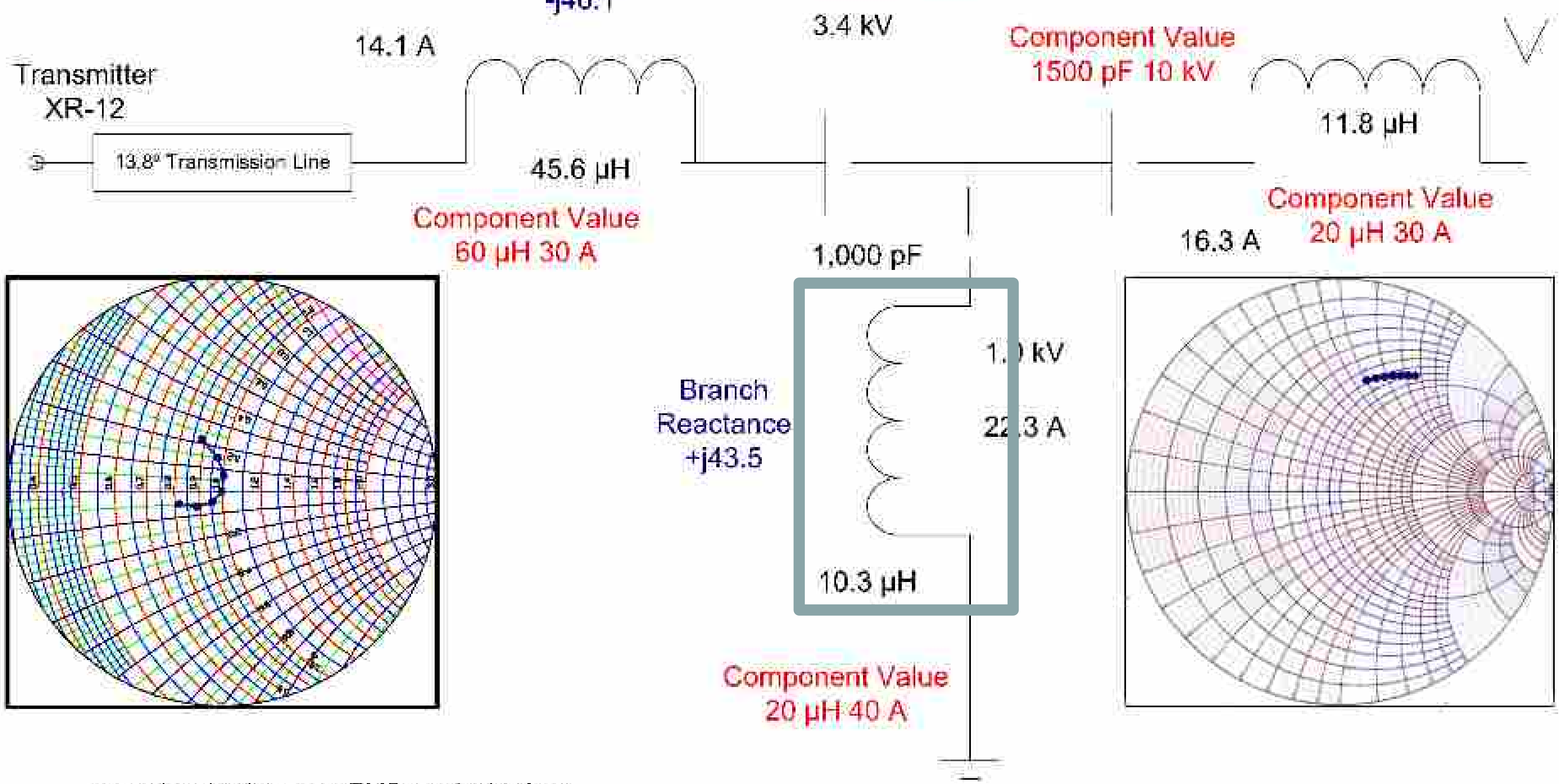


Add series 1500 pF capacitor

Moves us to 37.7 - j 44 Ohms

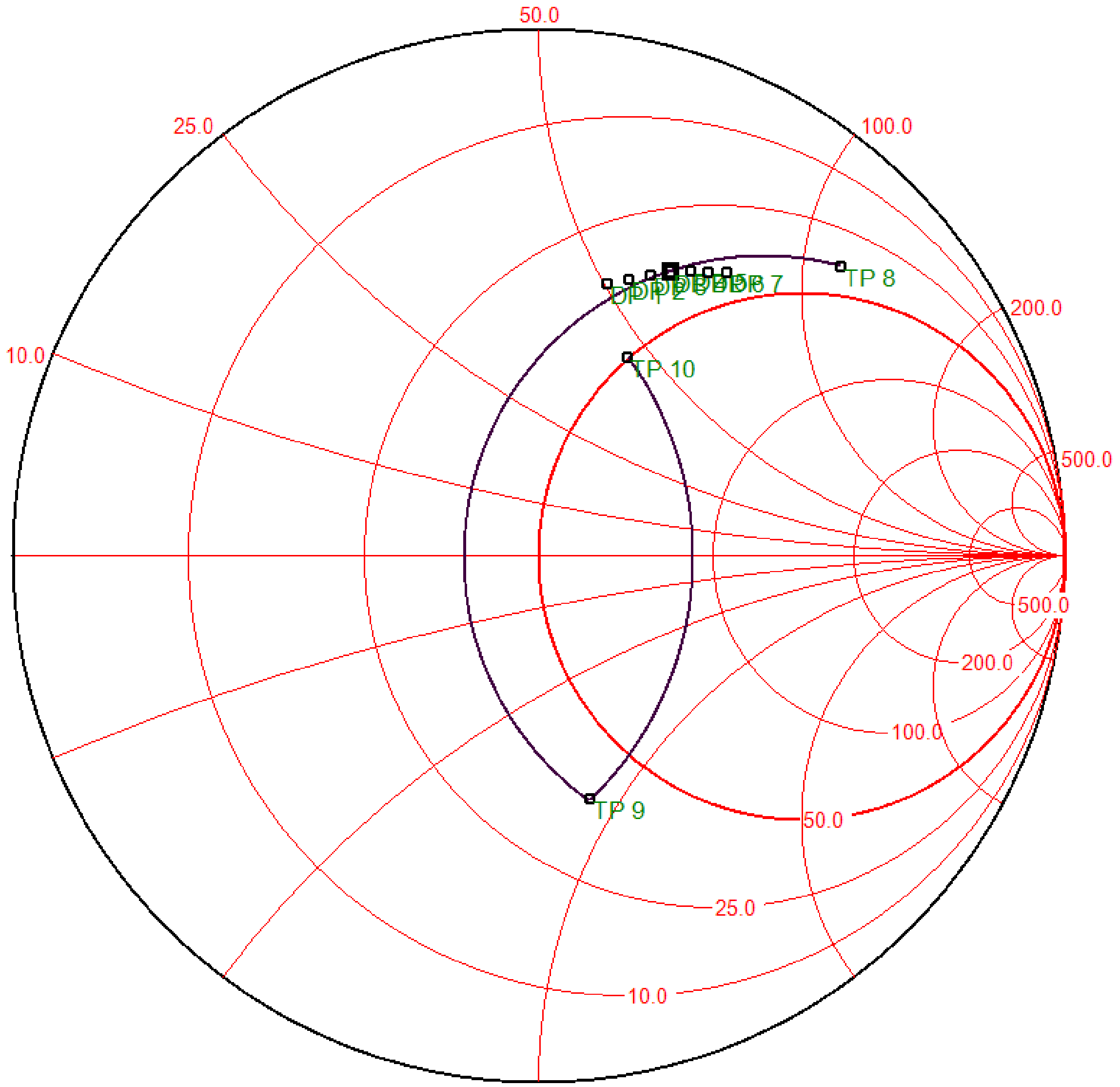
Frequency	Impedance		
(kHz)	Resistance	Reactance	VSWR
655	44.3	11.0	1.299
660	48.5	7.7	1.173
665	50.3	3.8	1.079
670	50.0	0.0	1.000
675	47.7	-2.4	1.070
680	44.4	-3.2	1.146
685	40.9	-2.4	1.232

KDLG	Measured	
Freq (kHz)	R	X
655.0	34.8	50.5
660.0	35.8	54.8
665.0	36.8	59.0
670.0	37.7	63.4
675.0	38.8	67.7
680.0	40.0	72.1
685.0	41.2	76.5



current and voltage are RMS nominal values
use safety factors of 1.7 for current and 3.5 for voltage

IBOC Phase Rotation and Bandwidth Correction

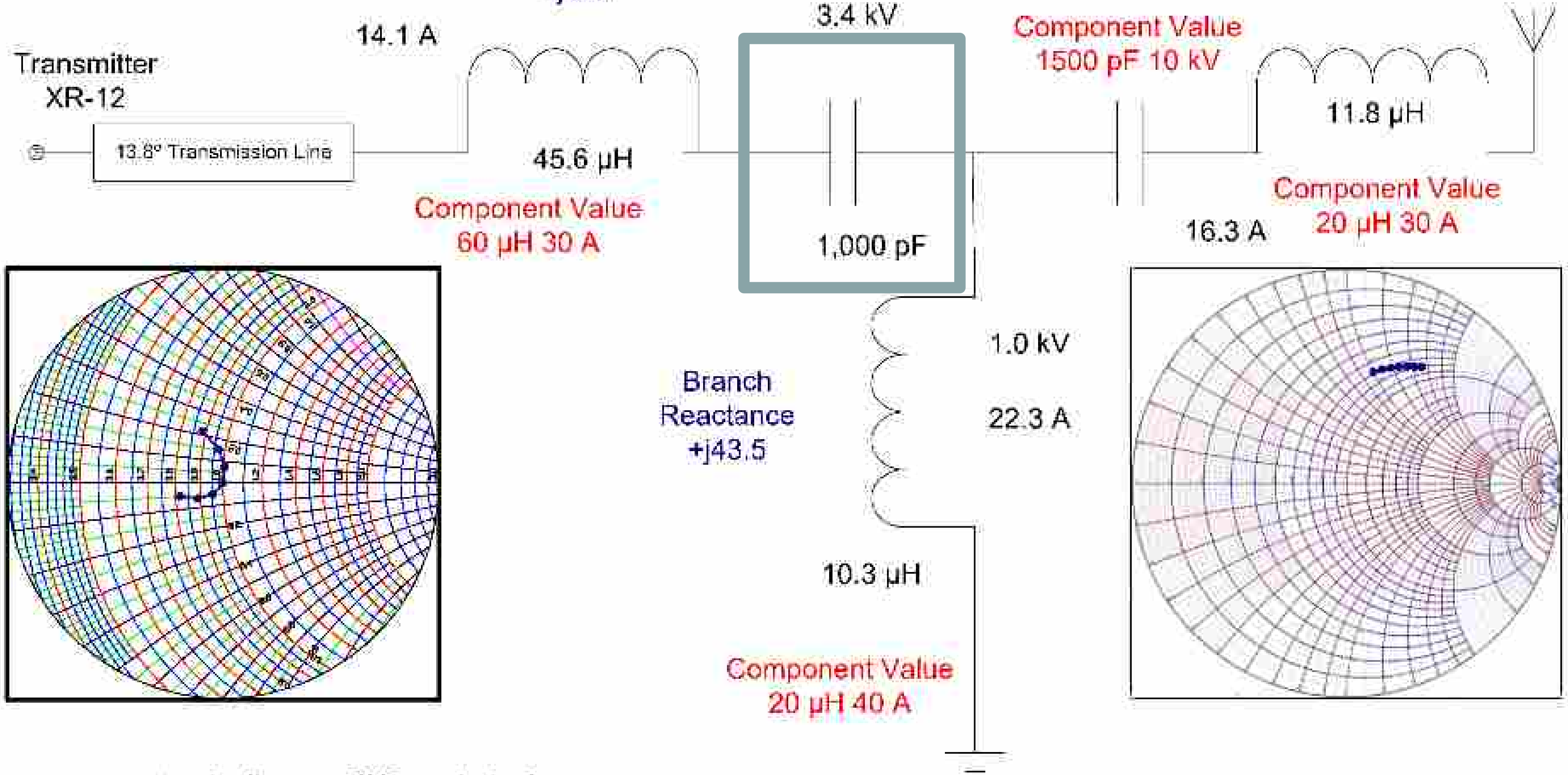


Add shunt coil 10.3 µH inductor

Moves us to 49.7 + j 45.5 Ohms

Frequency (kHz)	Impedance Resistance	Reactance	VSWR
655	44.3	11.0	1.299
660	48.5	7.7	1.173
665	50.3	3.8	1.079
670	50.0	0.0	1.000
675	47.7	-2.4	1.070
680	44.4	-3.2	1.146
685	40.9	-2.4	1.232

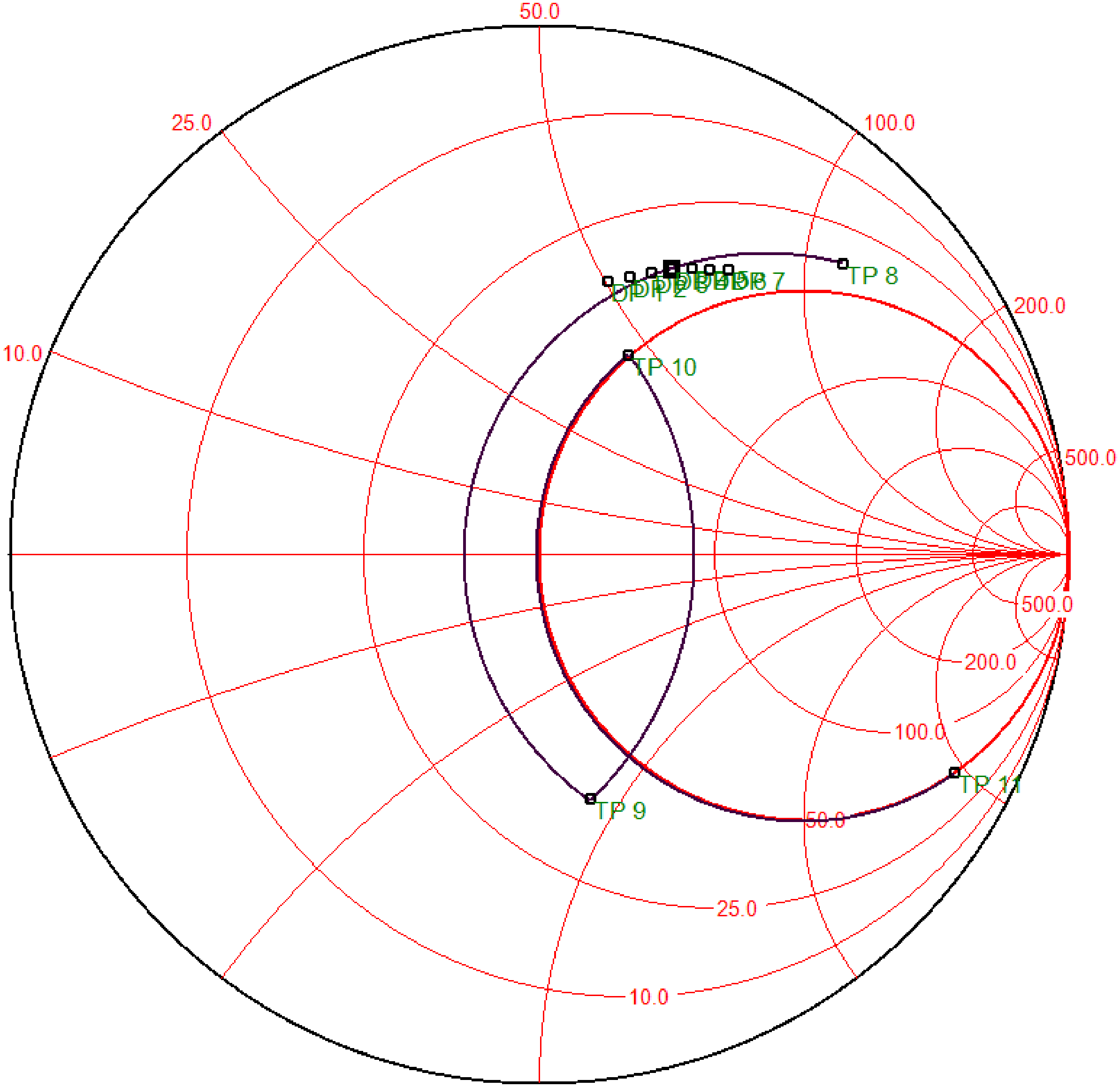
KDLG Freq (kHz)	Measured R	X
655.0	34.8	50.5
660.0	35.8	54.8
665.0	36.8	59.0
670.0	37.7	63.4
675.0	38.8	67.7
680.0	40.0	72.1
685.0	41.2	76.5



current and voltage are RMS nominal values
use safety factors of 1.7 for current and 3.5 for voltage

IBOC Phase Rotation and
Bandwidth Correction
KDLG, 670 kHz, 10 kW Dillingham, AK

TRANSMISSION TALK TUESDAY

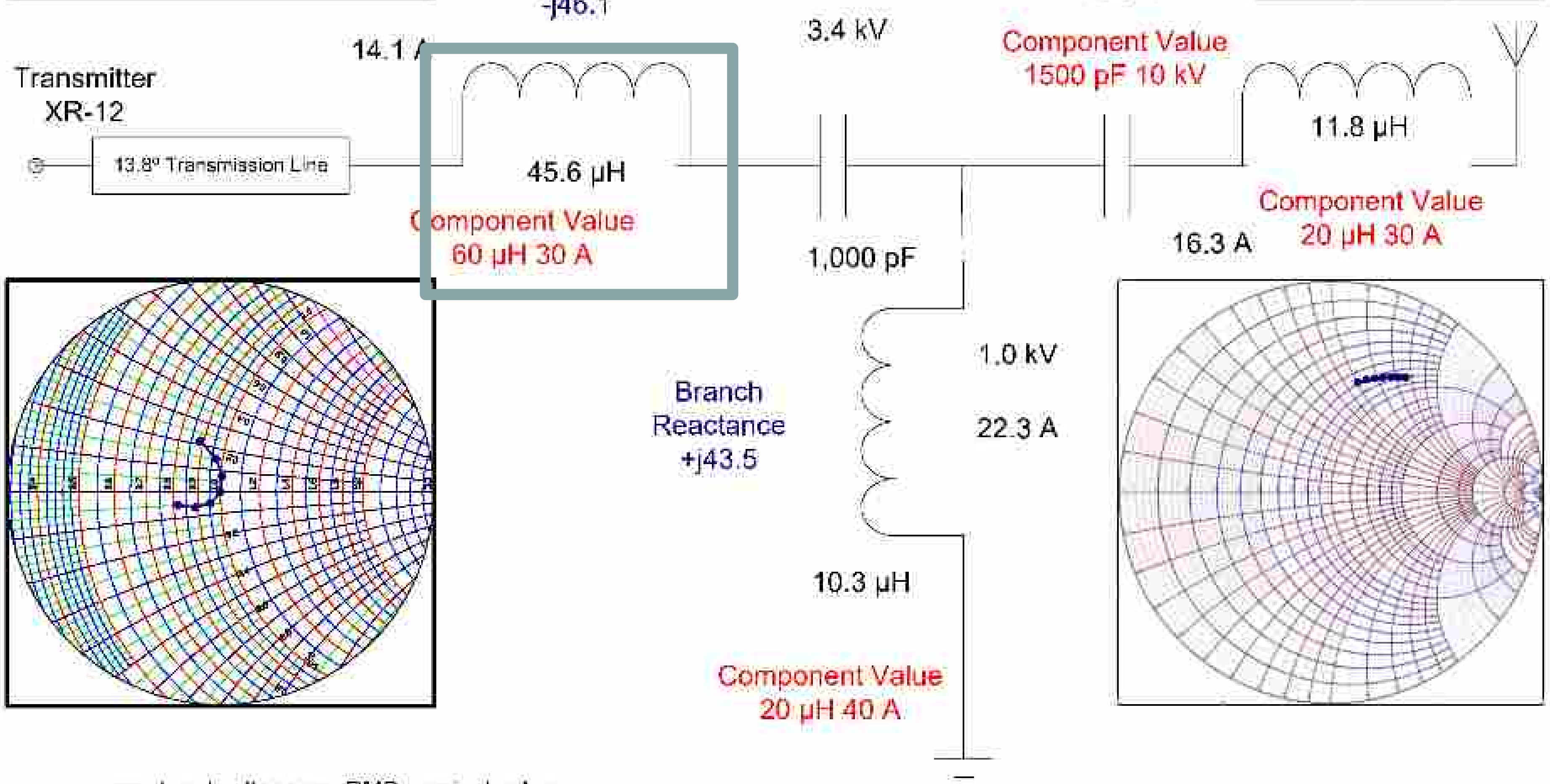


Add series 1000 pF capacitor

Moves us to 49.7 - j 190.5 Ohms

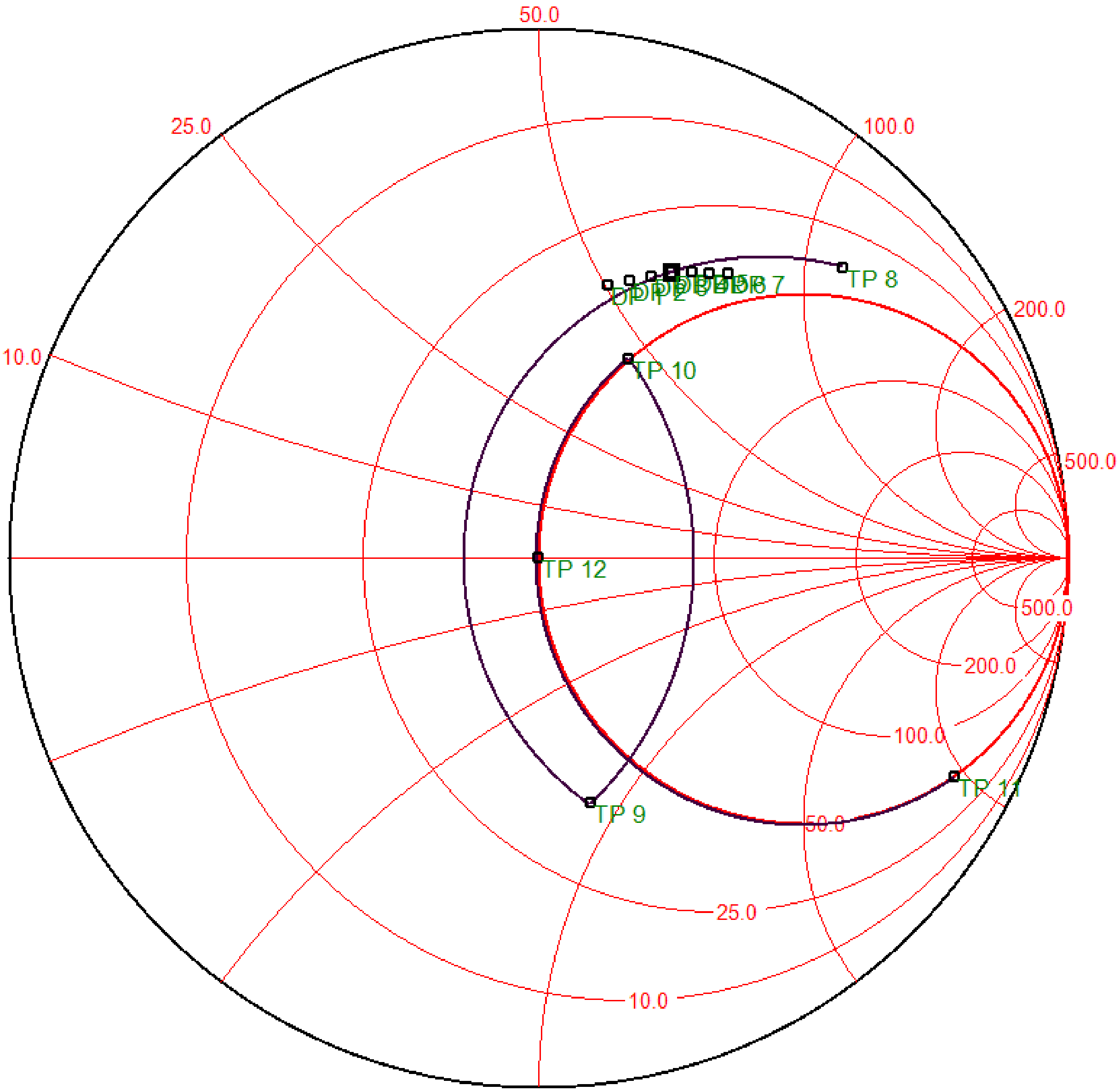
Frequency (kHz)	Impedance Resistance	Reactance	VSWR
655	44.3	11.0	1.299
660	48.5	7.7	1.173
665	50.3	3.8	1.079
670	50.0	0.0	1.000
675	47.7	-2.4	1.070
680	44.4	-3.2	1.146
685	40.9	-2.4	1.232

KDLG Freq (kHz)	Measured R	X
655.0	34.8	50.5
660.0	35.8	54.8
665.0	36.8	59.0
670.0	37.7	63.4
675.0	38.8	67.7
680.0	40.0	72.1
685.0	41.2	76.5



current and voltage are RMS nominal values
use safety factors of 1.7 for current and 3.5 for voltage

IBOC Phase Rotation and Bandwidth Correction
KDLG, 670 kHz, 10 kW Dillingham, AK

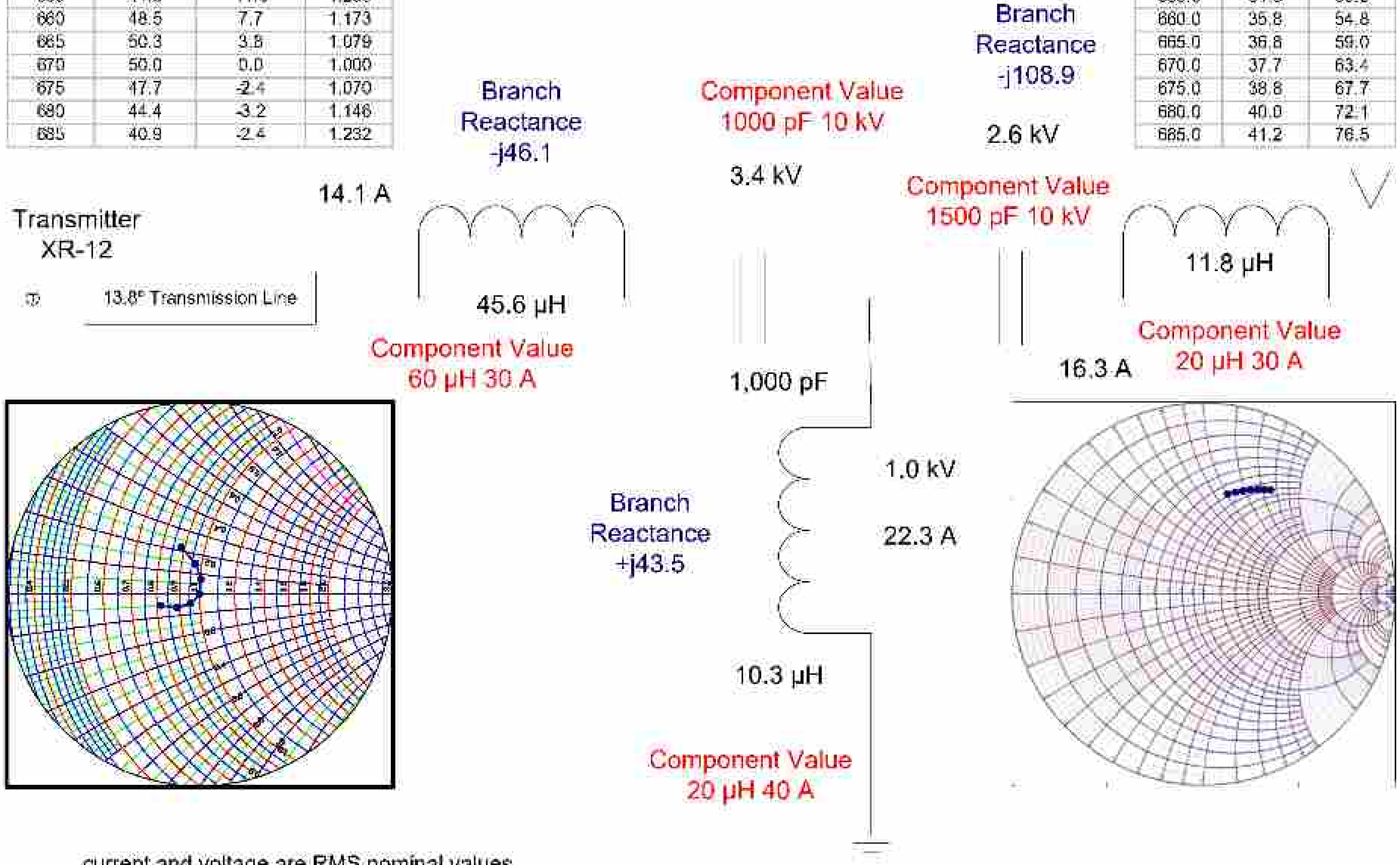


Add series 45.6 µH inductor

Moves us to 49.7 + j 0.2 Ohms

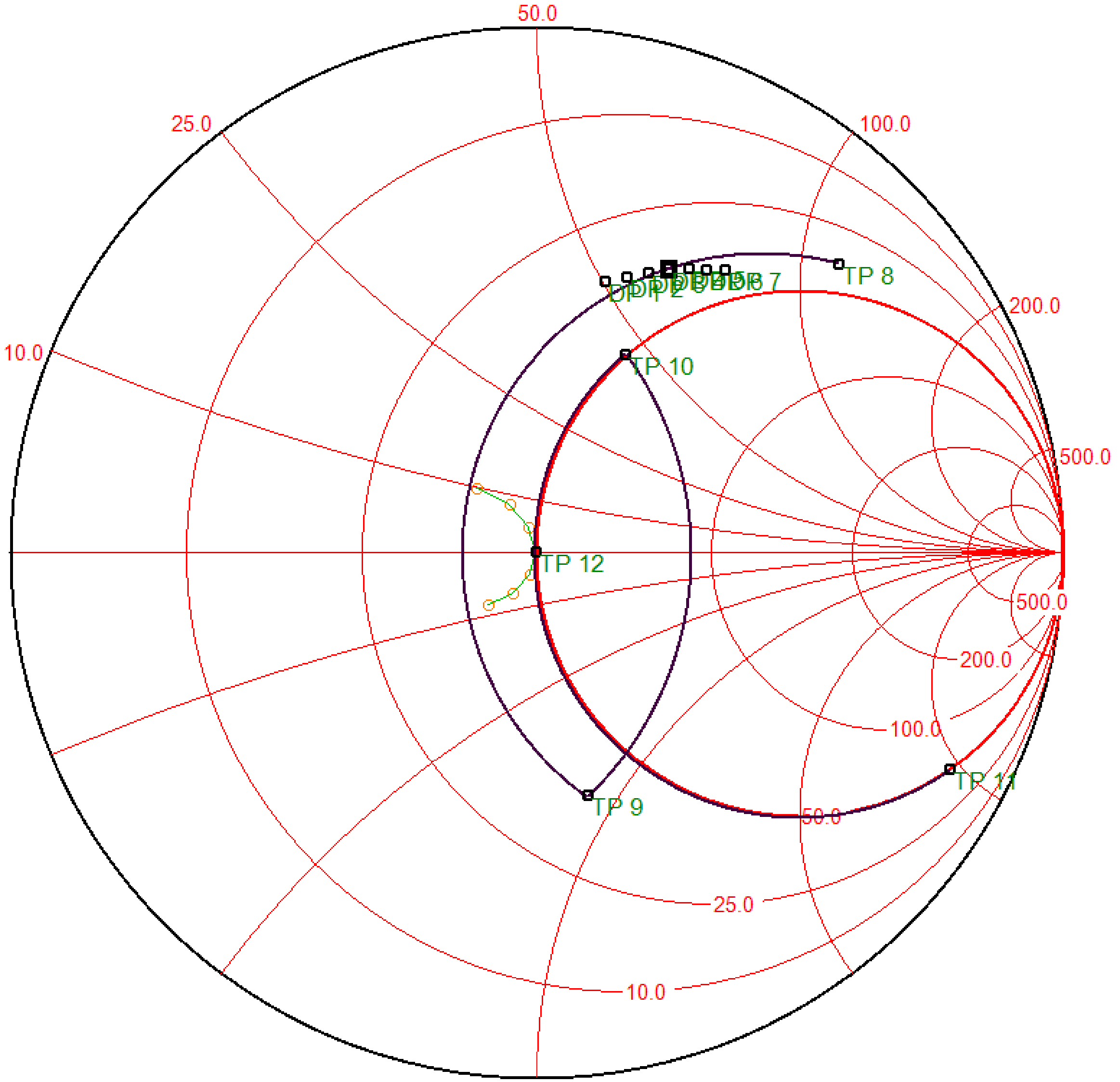
Frequency (kHz)	Impedance Resistance	Reactance	VSWR
655	44.3	11.0	1.299
660	48.5	7.7	1.173
665	50.3	3.8	1.079
670	50.0	0.0	1.000
675	47.7	-2.4	1.070
680	44.4	-3.2	1.146
685	40.9	-2.4	1.232

KDLG Freq (kHz)	Measured R	X
655.0	34.8	50.5
660.0	35.8	54.8
665.0	36.8	59.0
670.0	37.7	63.4
675.0	38.8	67.7
680.0	40.0	72.1
685.0	41.2	76.5



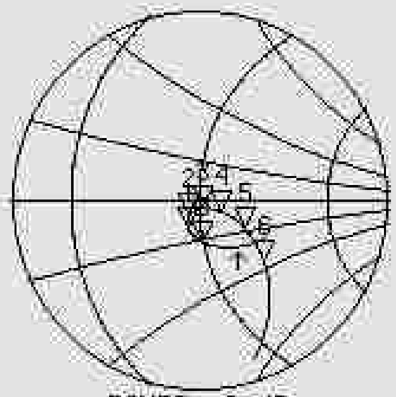
current and voltage are RMS nominal values
use safety factors of 1.7 for current and 3.5 for voltage

IBOC Phase Rotation and
Bandwidth Correction
KDLG, 670 kHz, 10 kW Dillingham, AK



Calculating side bands

SP 1	(38.482 + j9.867) Ω	Q=0.256	655.000kHz
SP 2	(44.072 + j8.317) Ω	Q=0.189	660.000kHz
SP 3	(47.981 + j4.927) Ω	Q=0.103	665.000kHz
SP 4	(49.650 + j0.274) Ω	Q=0.006	670.000kHz
SP 5	(48.394 - j4.038) Ω	Q=0.083	675.000kHz
SP 6	(45.017 - j7.051) Ω	Q=0.157	680.000kHz
SP 7	(40.640 - j8.257) Ω	Q=0.203	685.000kHz

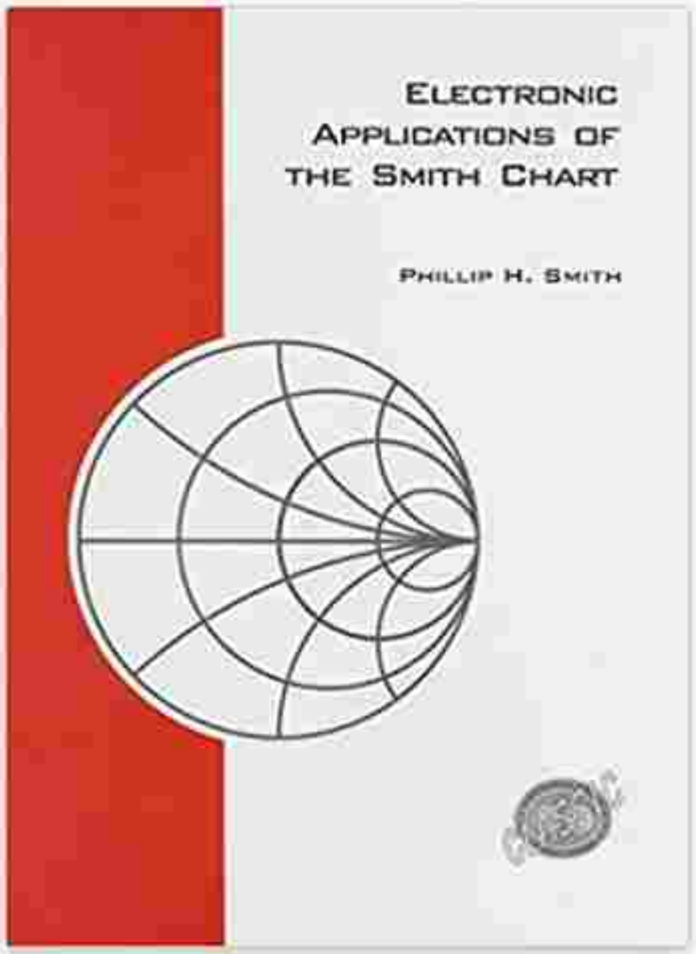


IF BW 300 Hz
START 535 kHz

POWER -6 dBm

SWP 2.967 sec
STOP 585 kHz

N	SWP PARAM	VAL	AUX	EXTRA
0	545 kHz	50.175 Ω	-11.32 Ω	25.797 nF
1	550 kHz	47.155 Ω	-7.2862 Ω	39.715 nF
2	555 kHz	47.463 Ω	-3.8503 Ω	74.48 nF
3	560 kHz	50.826 Ω	-2.1784 Ω	130.46 nF
4	565 kHz	56.277 Ω	-3.3165 Ω	84.935 nF
5	570 kHz	63.194 Ω	-9.5886 Ω	29.12 nF
6	575 kHz	66.6 Ω	-22.454 Ω	12.327 nF



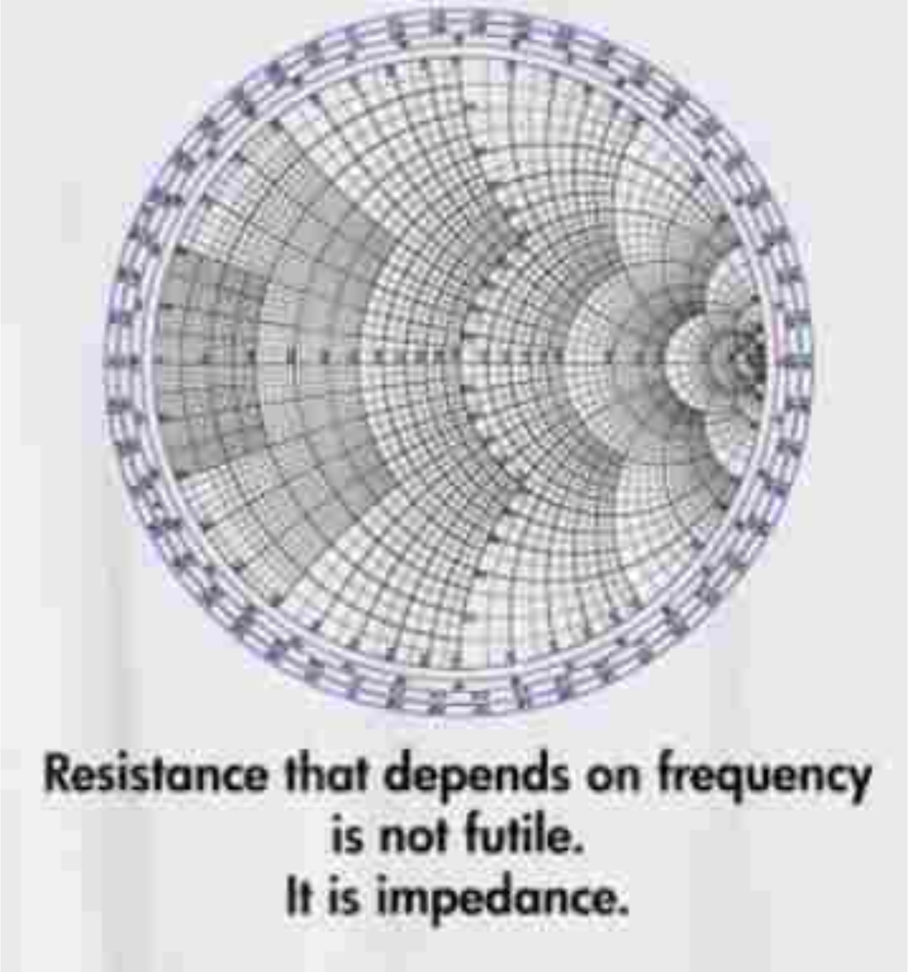
Out of Print $180 on ebay.

Per Unit 1.0022 –j 0.0154 or 50.11 –j 0.77 ohms.   Close enough!

Per Unit 0.9967 +j 0.0076 or 49.83 +j 0.38 ohms. Close enough!

Per Unit 0.9943 +j 0.0174 or 49.71 – j 0.87 ohms.   Close enough!

TRANSMISSION TALK TUESDAY


Resistance that depends on frequency
is not futile.
It is impedance.


Math Tattoos
mathtattoos.com

Digital transmission signal quality metrics

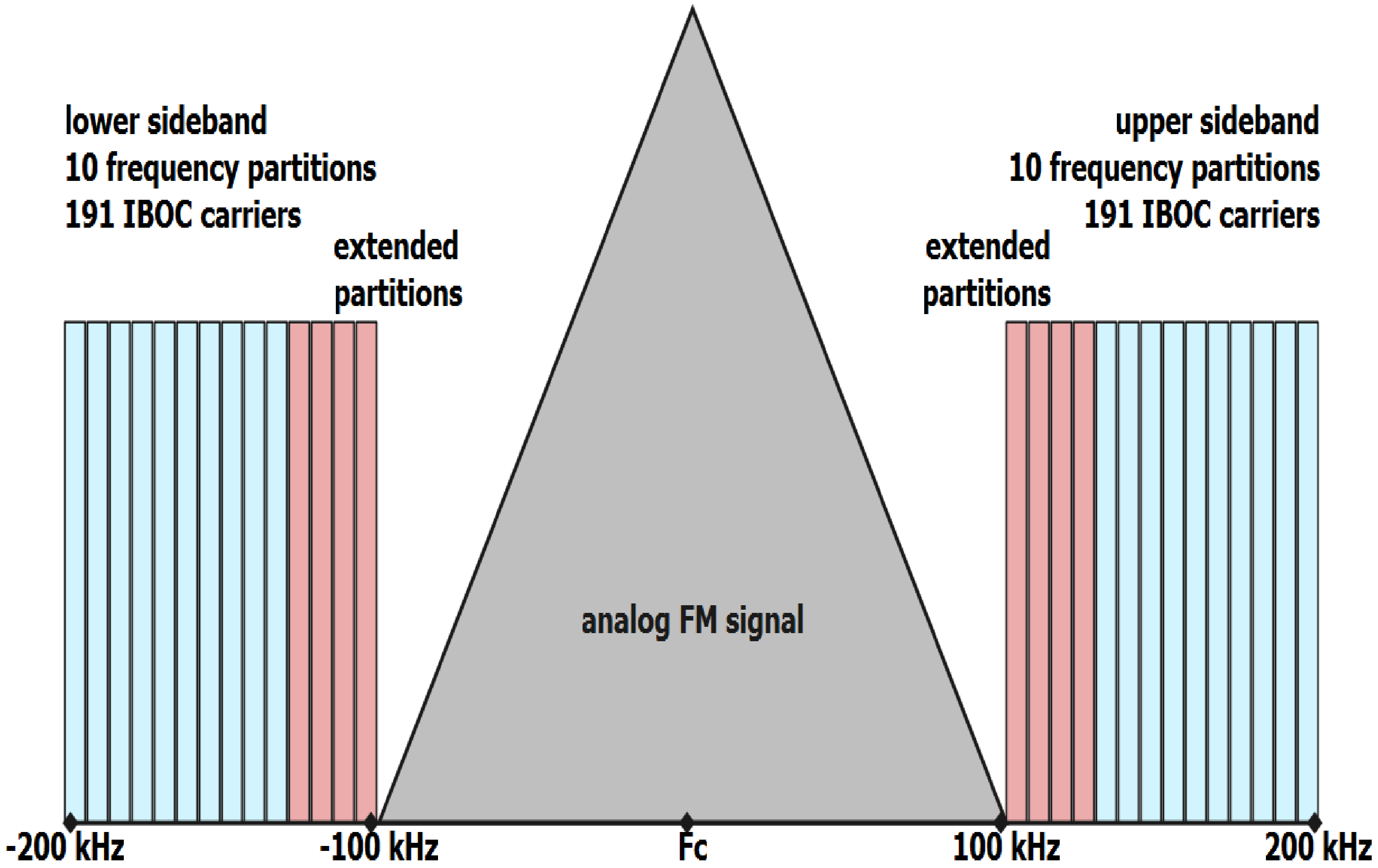
MER – Modulation Error ratio

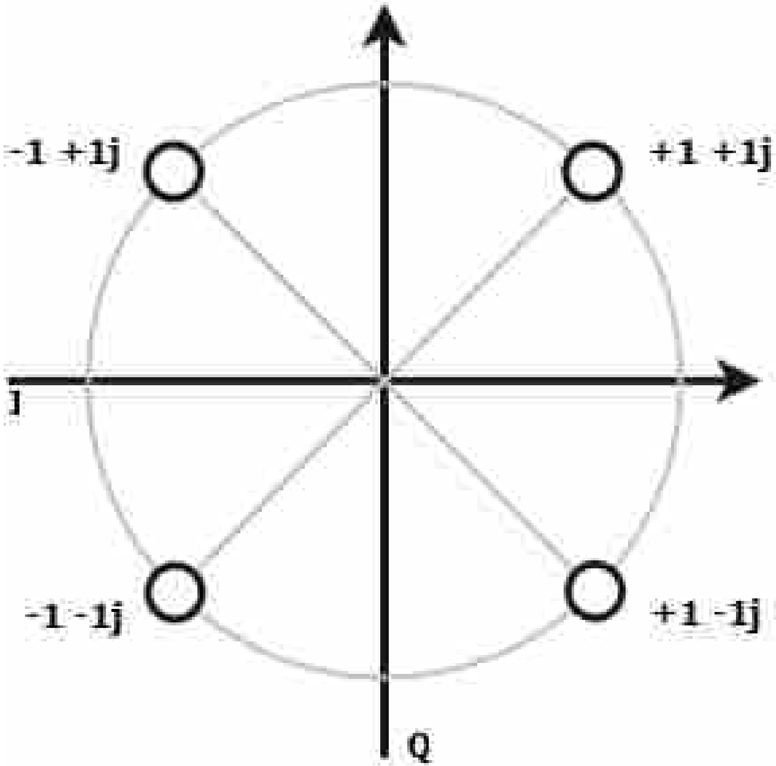
$$\mathrm{MER(dB)} = 10\log_{10}\left(\frac{P_{\mathrm{signal}}}{P_{\mathrm{error}}}\right)$$

$$\mathrm{MER}(\%) = \sqrt{\frac{P_{\mathrm{error}}}{P_{\mathrm{signal}}}} \times 100\%$$

In dB it is desired to have a MER of 14dB or better

IBOC Signaling

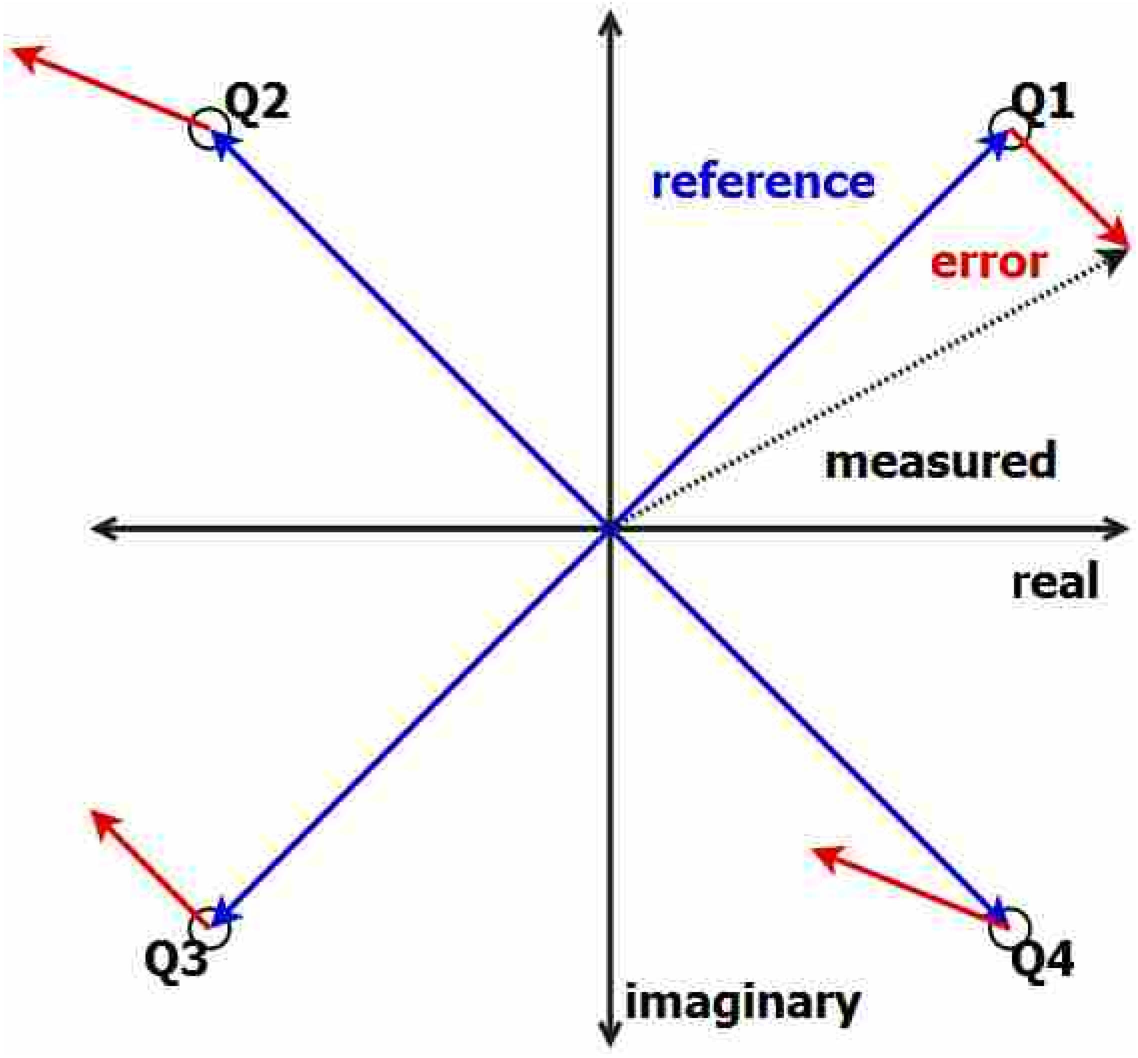




data carriers QPSK

ref carriers BPSK

Modulation Error Ratio (MER)



Requires IBOC demodulation

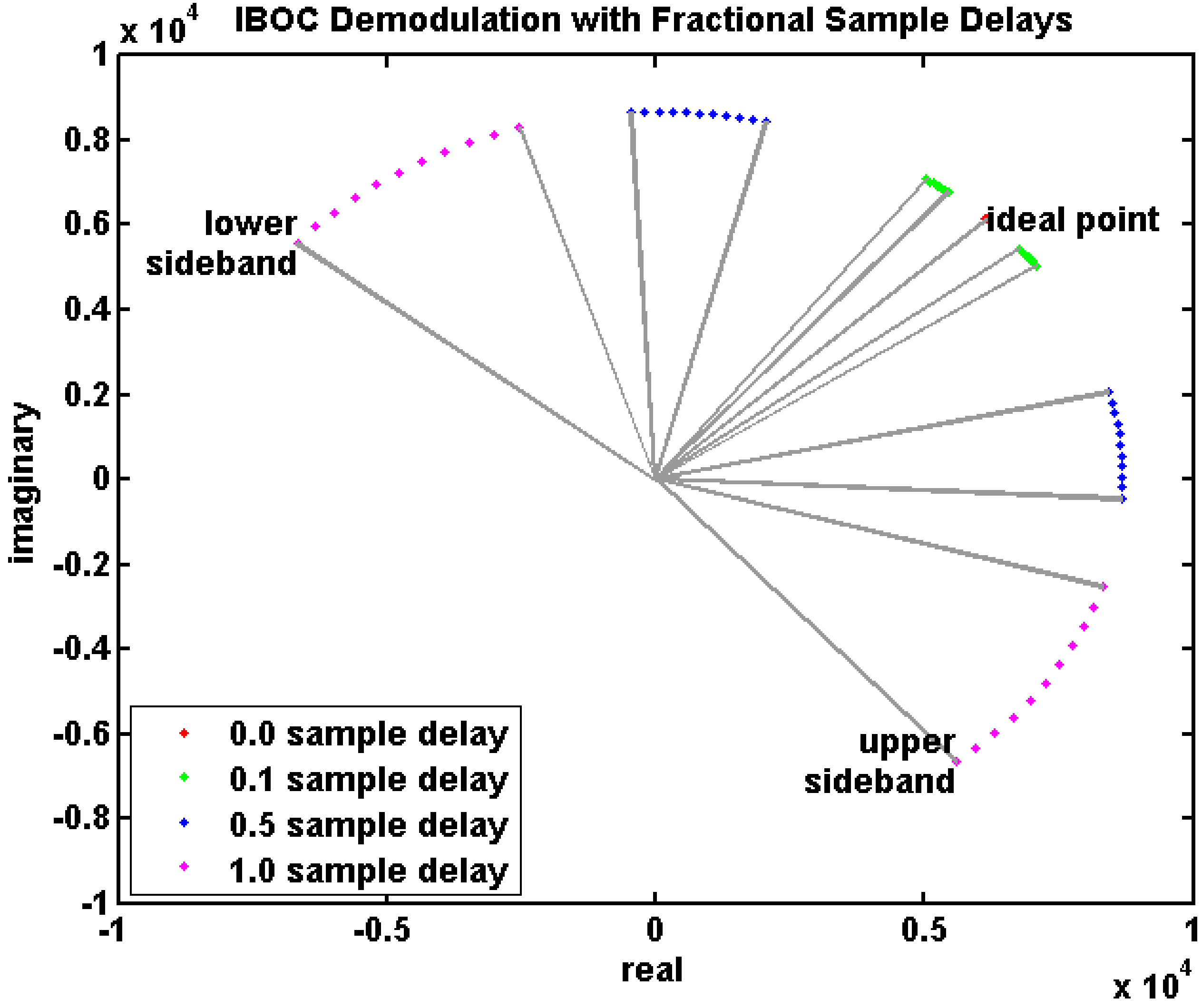
Modulation Error Ratio:

$$MER(dB) = 10log_{10}(\frac{P_{reference}}{P_{error}})$$

Error Vector Magnitude:

$$EVM(\%) = 100\%\sqrt{\frac{P_{error}}{P_{reference}}}$$

Fractional Sample Delays

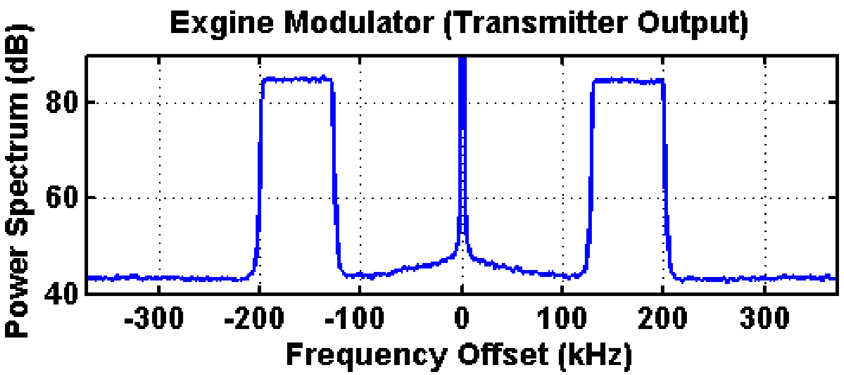


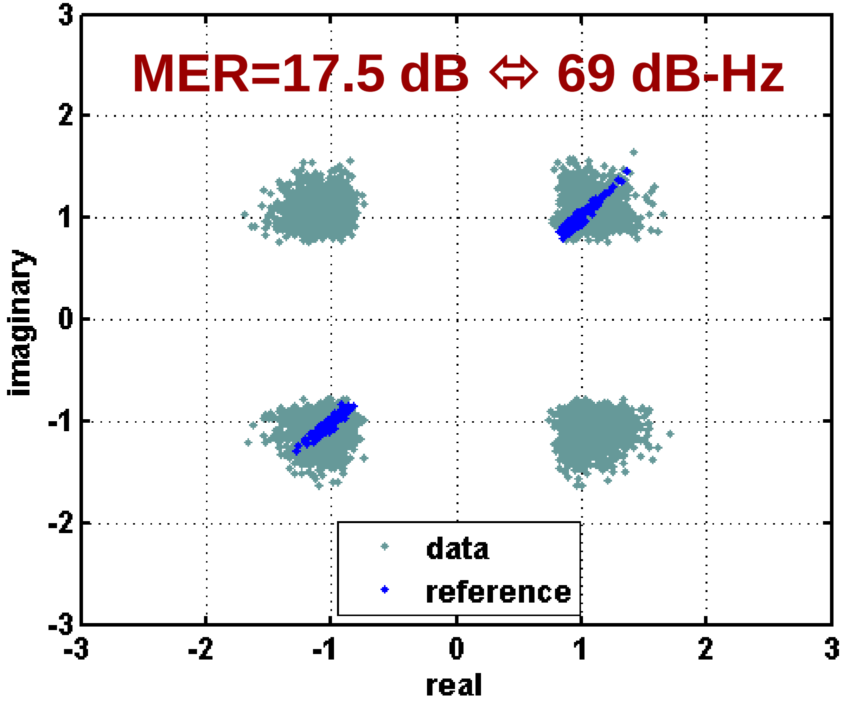
Signal capture and sample rate conversion may cause fractional sample delays

$$x[n - n_d] \longleftrightarrow e^{-j\omega n_d} X(e^{j\omega})$$

delay error ⇔ phase error

Defining Acceptable Quality





\+

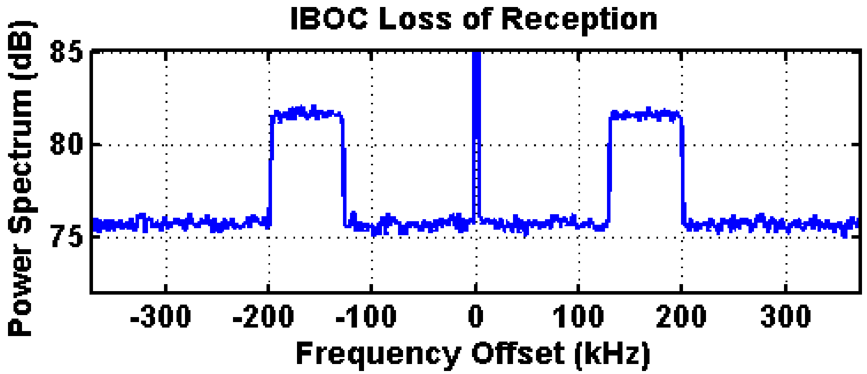
additive

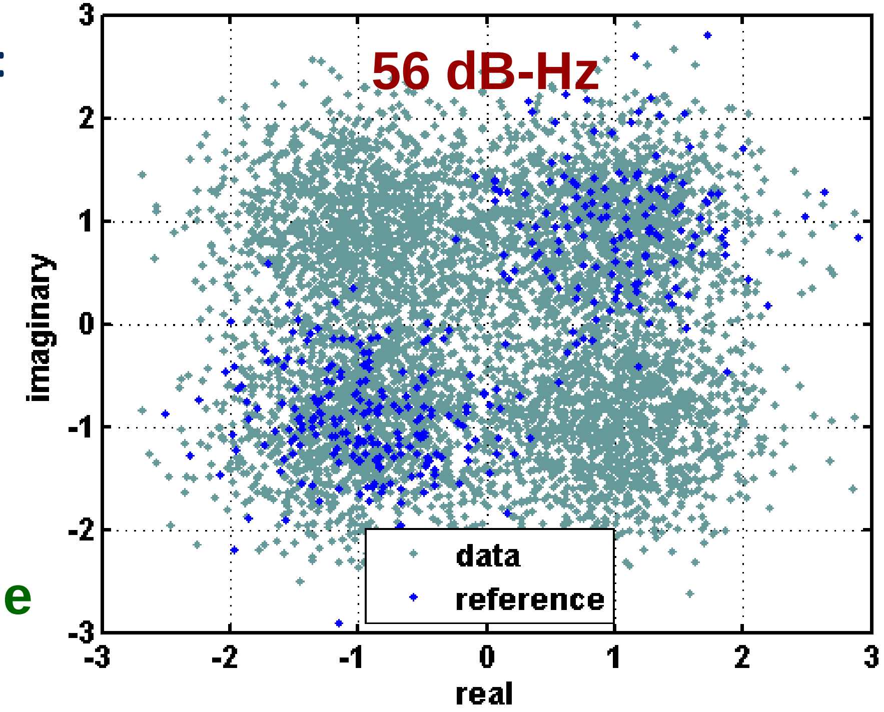
channel

noise

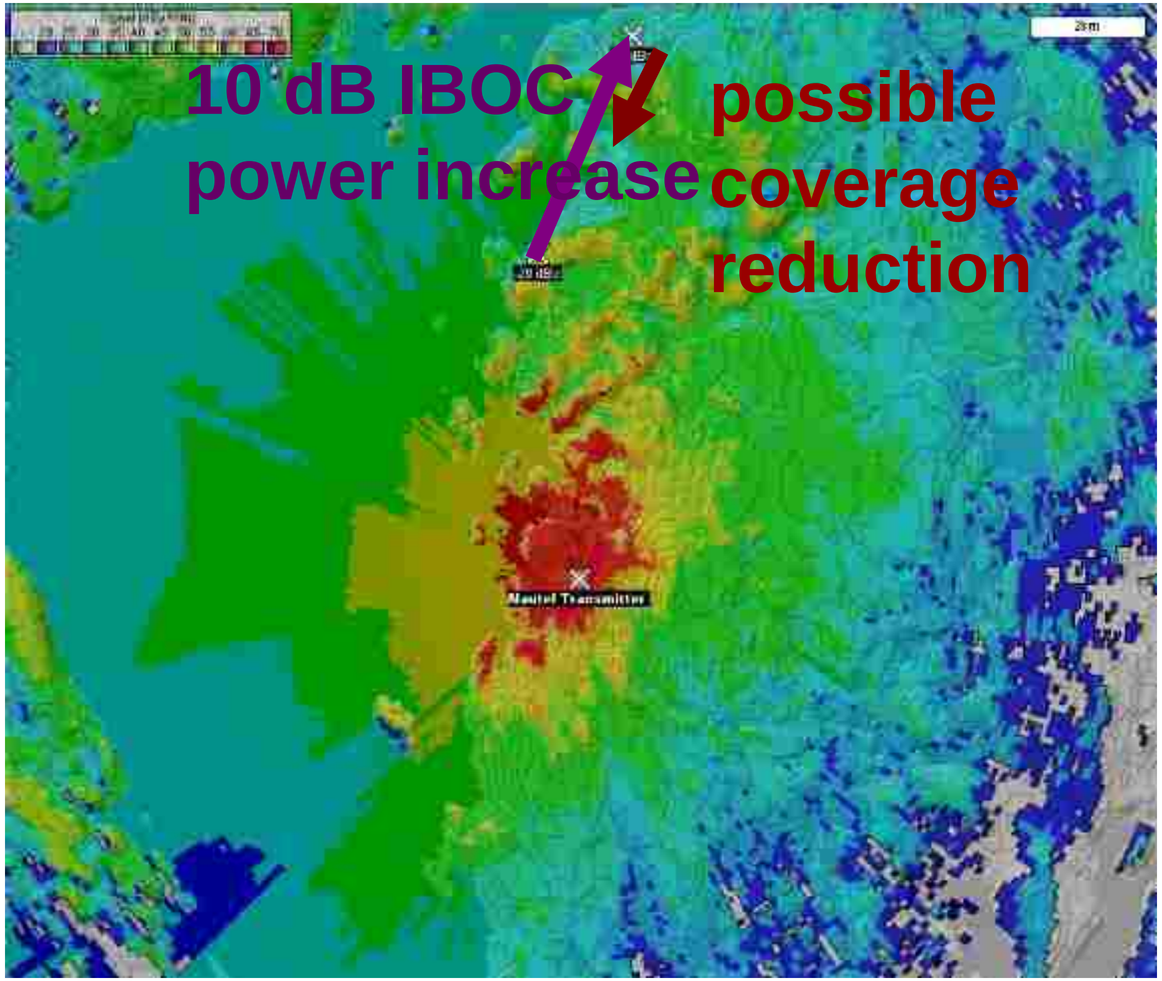
=

$-10 \log10^{(10-56/10-10-69/10)}$
= 56.22 dB-Hz
0.22 dB loss in coverage





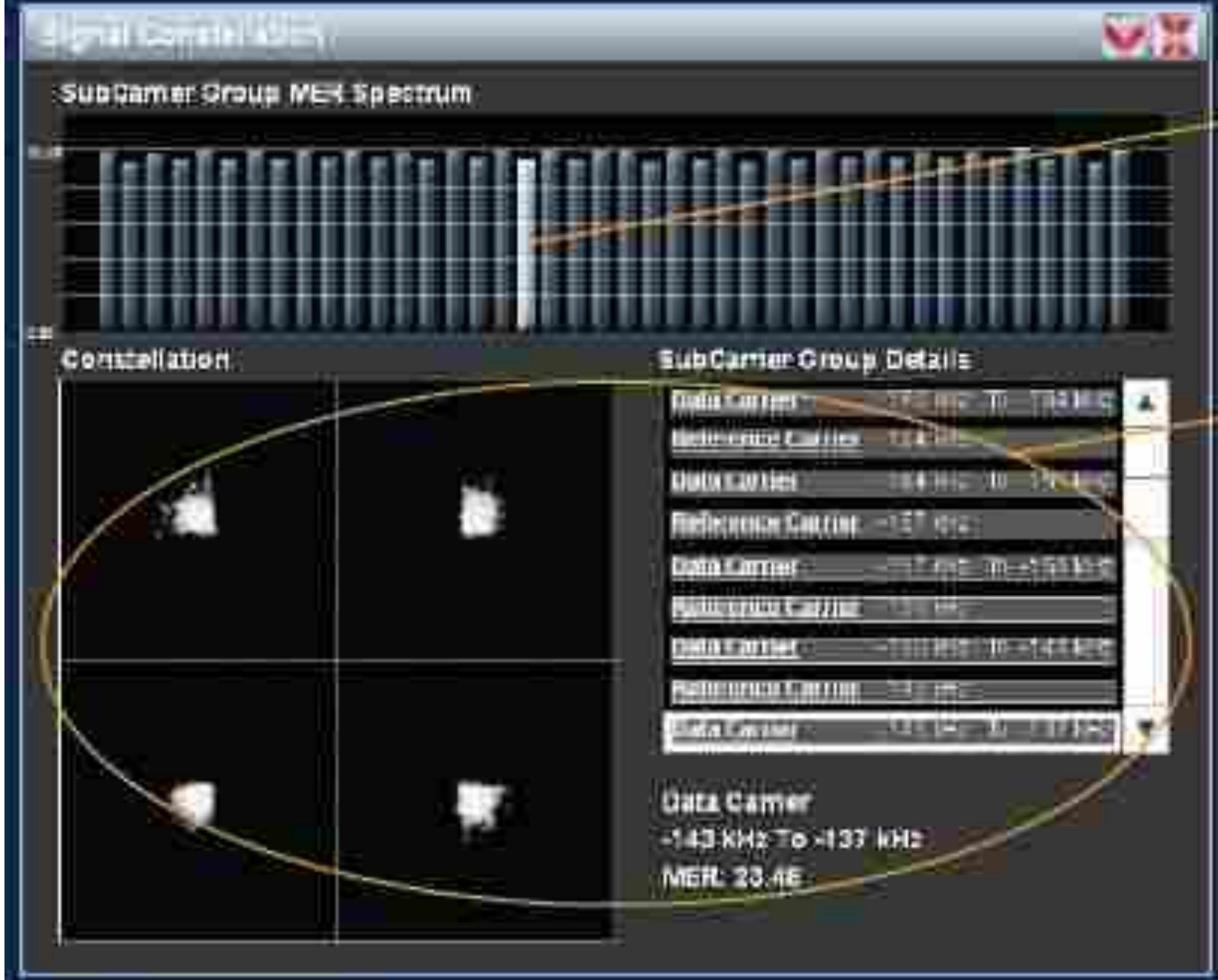
Defining Acceptable Quality



Average MER_{data}	Coverage Reduction
18 dB	0.22 dB
16 dB	0.31 dB
14 dB	0.48 dB
12 dB	0.74 dB
10 dB	1.13 dB
8 dB	1.73 dB

Exgine output

Specified limit



Signal Constellation View

Select a subcarrier using the mouse or AUI touchscreen

Full MER analysis shown for the subcarrier

Coverage

- MER can be impacted by various things
  - Bandwidth
  - Tuning
  - Interference

Photo credit: ERI (www.eriinc.com)

Online Information

Webinars
https://www.nautel.com/resources/webinars/

Nautel Waves Newsletter
https://www.nautel.com/newsletters/

YouTube
http://www.youtube.com/user/NautelLtd

Online Info, such as the Broadcasters' Desktop Resource
https://www.thebdr.net/

https://www.hatdaw.com/downloads.html

THANK YOU!

54 years of NAUTEL 1969 2023

TRANSMISSION TALK TUESDAY

nautel AM/FM Radio Transmitters