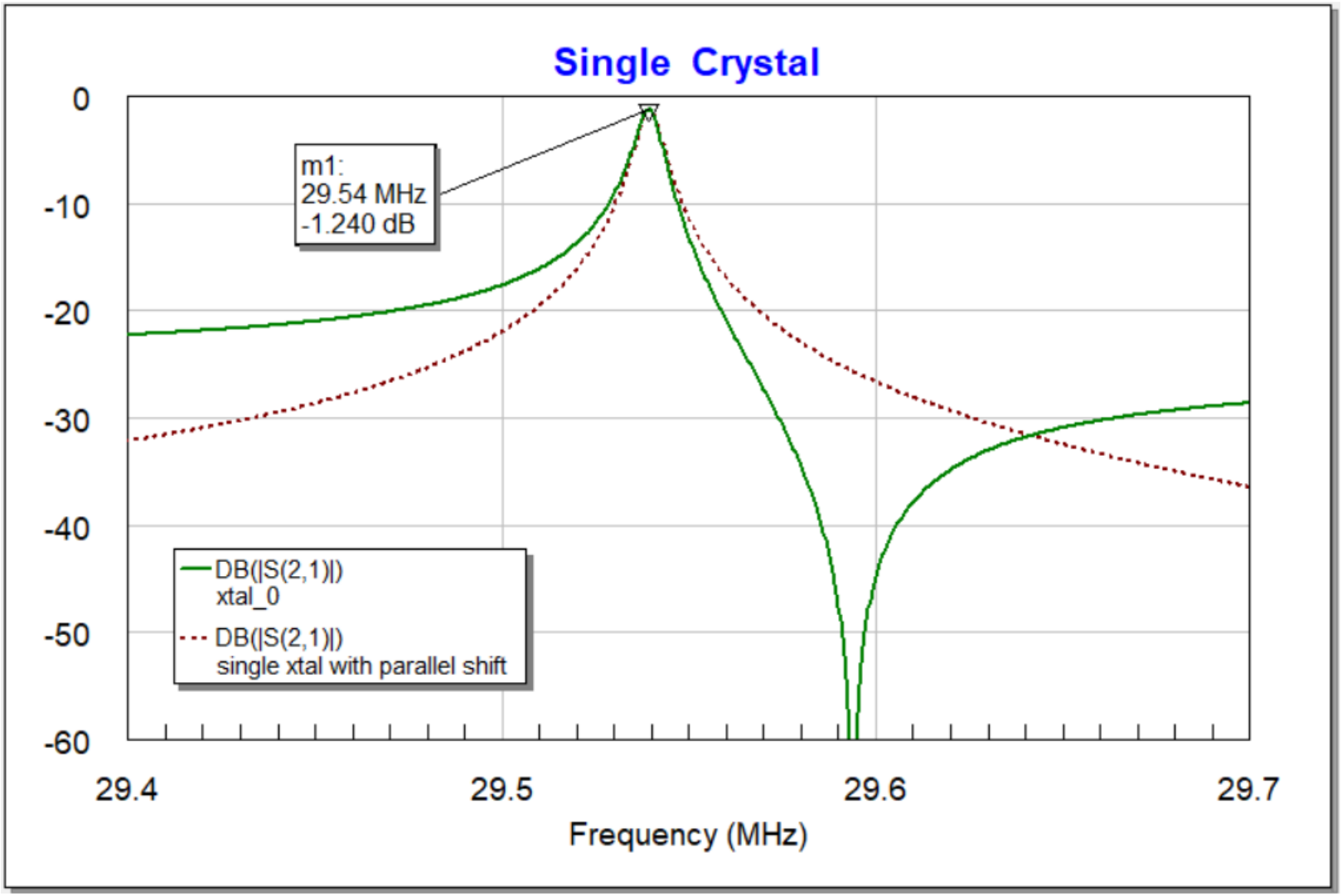

CRYSTAL FILTER
for 10M FRONT-END
February 2, 2019

ISOLATION CALCULATION

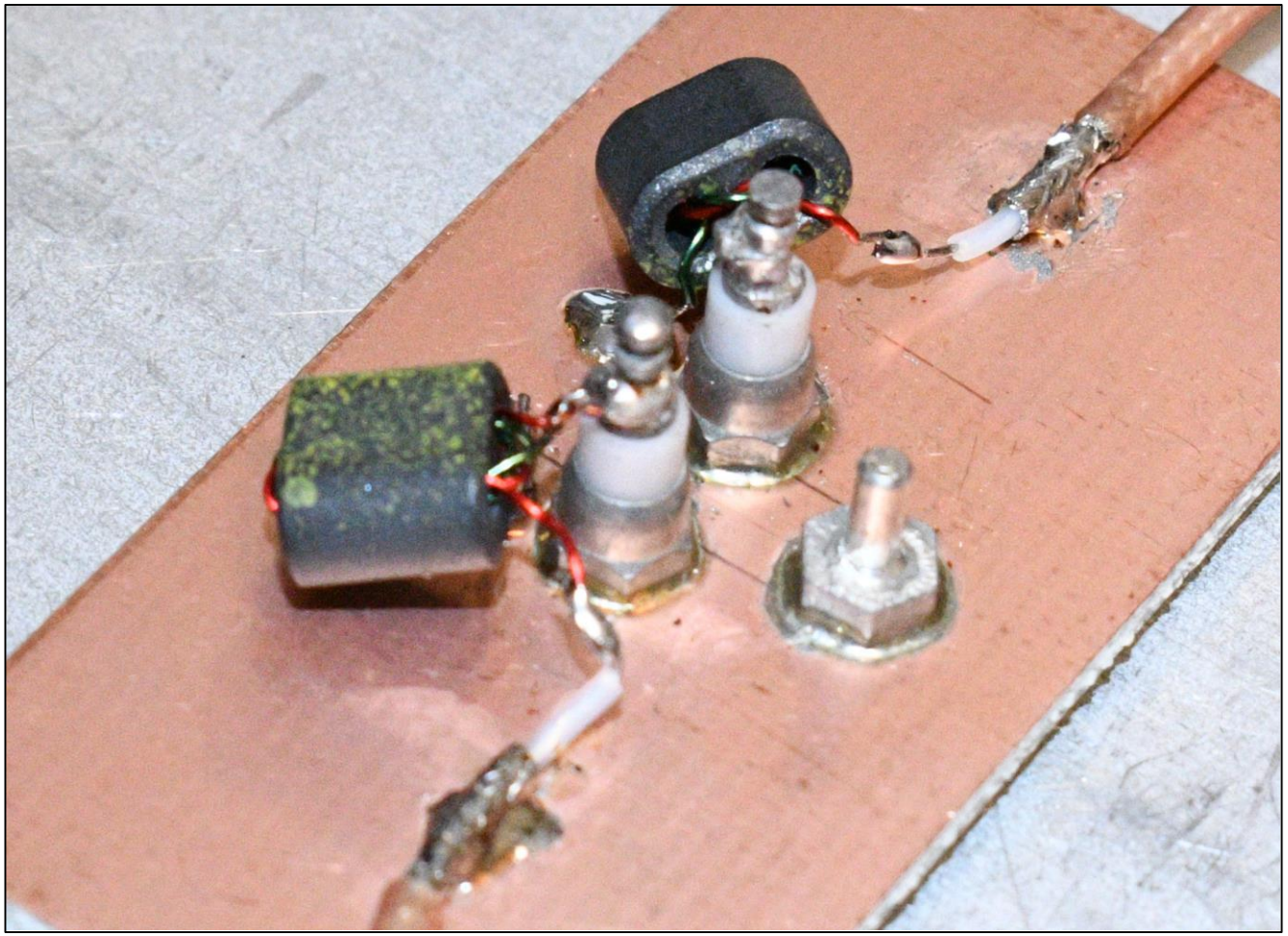
10 M (100 KHz Δ F)		
OK - no desense	-70	dBm
Threshold	-65	dBm
TX PWR	45	dBm
Needed Isolation	110	dB
Path Loss	80	dB
Margin	-30	dB

- Split site repeater
- TX - RX offset = 100 KHz
- Additional isolation required to prevent desense = 30 dB
- TX frequency = 29.640 MHz
- RX frequency = 29.540 MHz

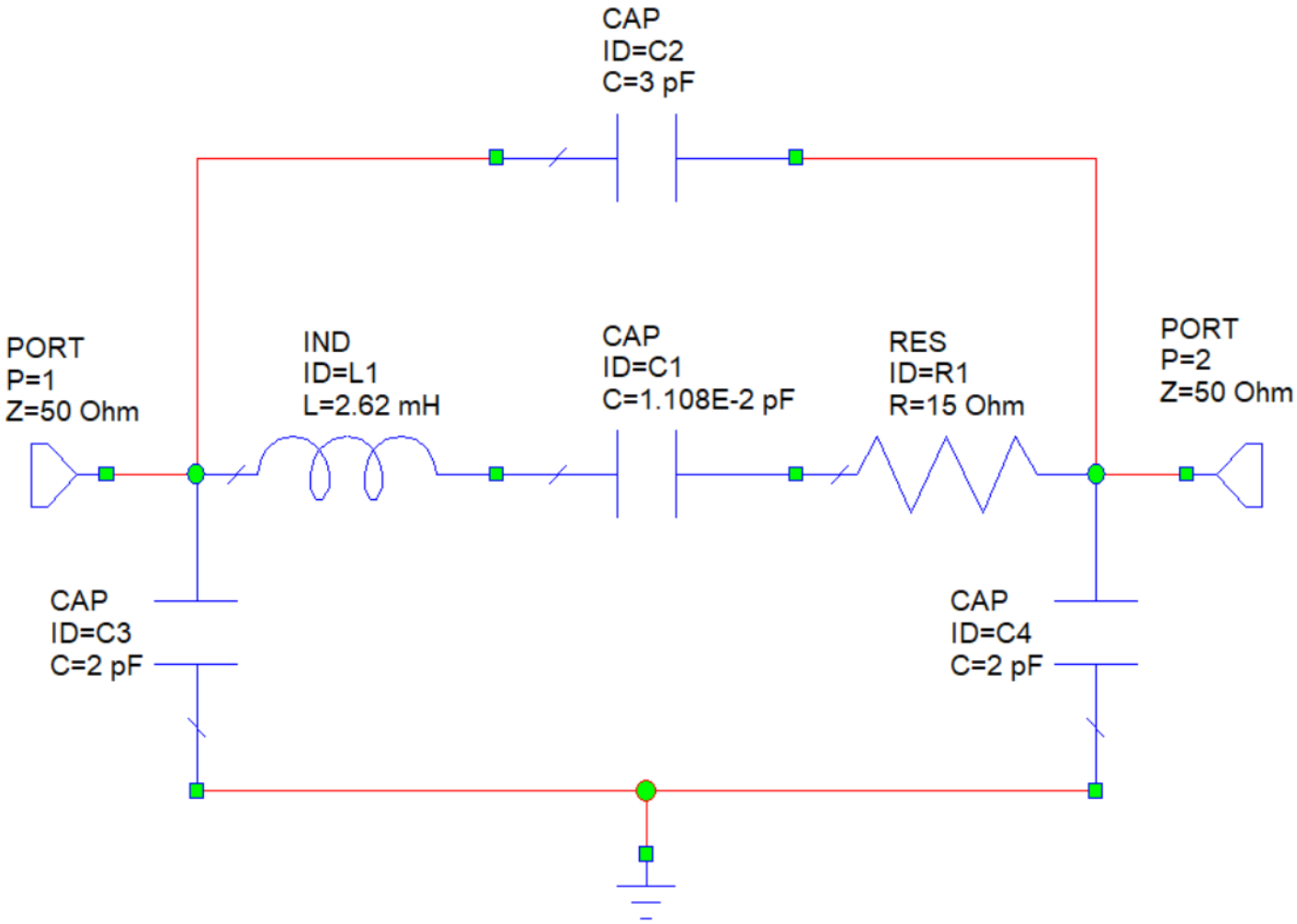
SIMULATED RESPONSE



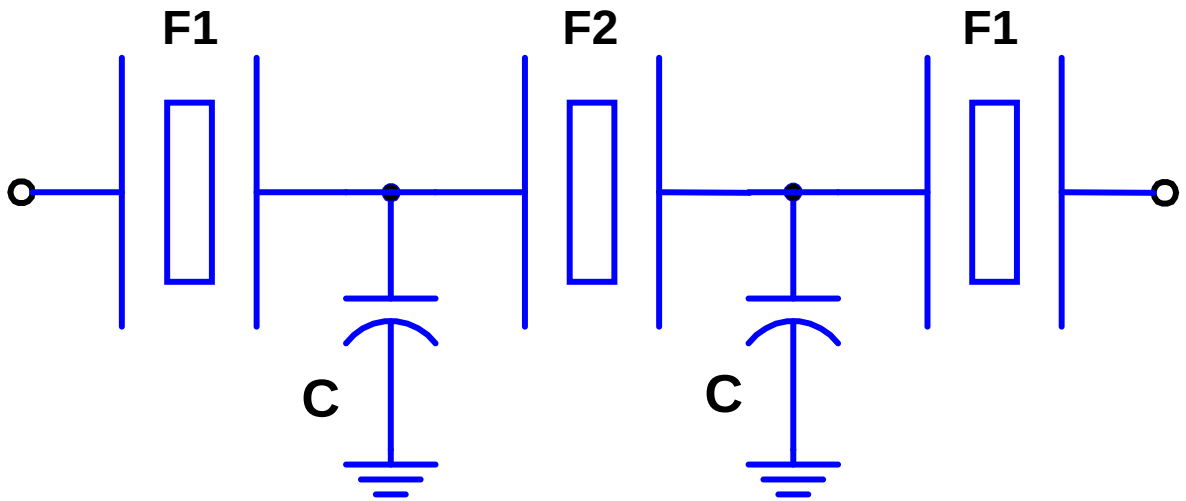
CHARACTERIZATION FIXTURE - 12.5 Ω



CRYSTAL EQUIVALENT CIRCUIT MODEL

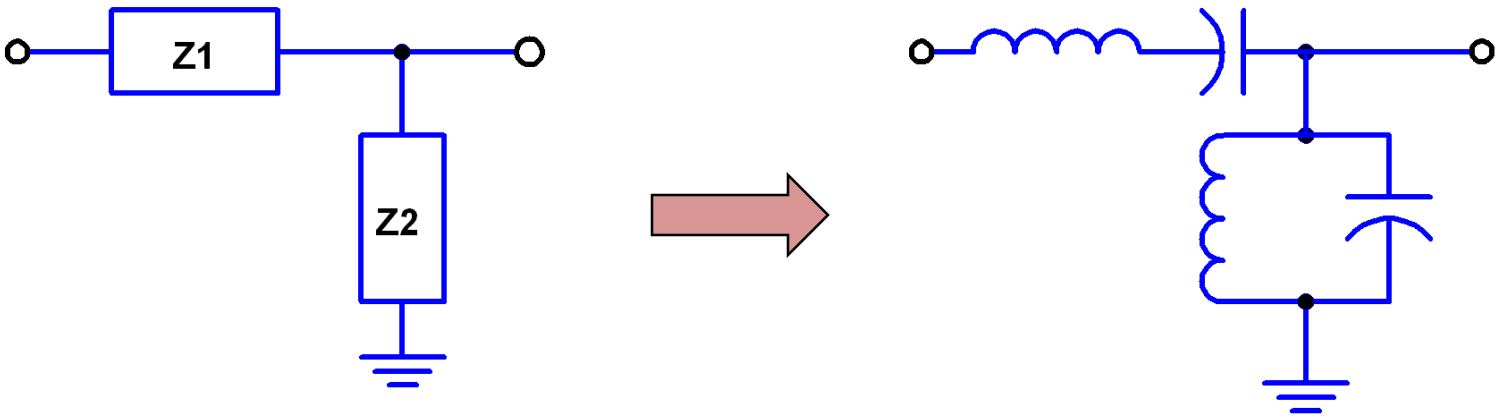


LADDER XTAL FILTER



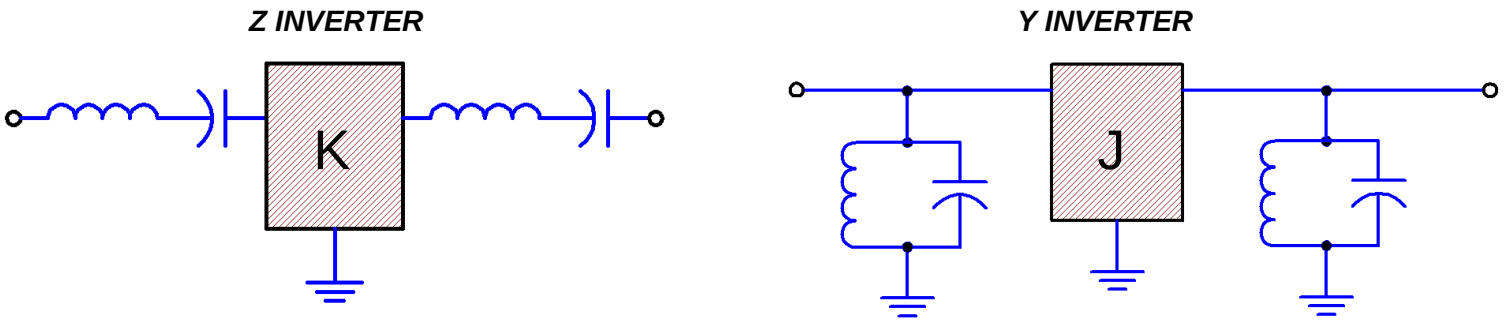
- Inter-resonator coupling set by shunt cap C
- Port impedance is higher than 50 Ω
- Resonators F1 and F2 are slightly below desired Fo

LADDER FILTER BASIC BUILDING BLOCK



- Passband: Z1 ⇨ *short* and Z2 ⇨ *open*
- Stopband: Z1 ⇨ *open* and Z2 ⇨ *short*

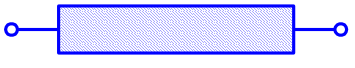
J and K INVERTERS PROVIDE REUSE OF RESONATOR TYPE



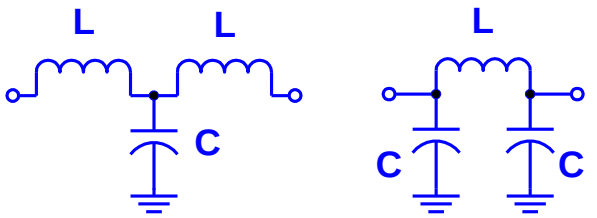
- Impedance inverter (K) with a series resonator behaves like a parallel resonator
- Admittance inverter (J) with a parallel resonator behaves like a series resonator
- Impedance/admittance inverter interface between similar resonators provides maximum stopband attenuation
- Most common impedance inverter is transmission line that is an odd multiples of $\lambda/4$

IMPEDANCE/ADMITTANCE INVERTERS

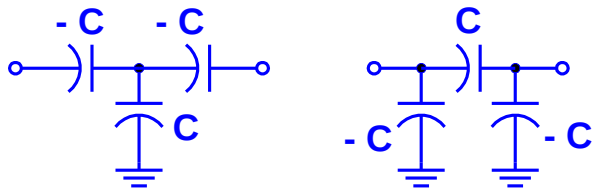
- Impedance (or admitance) inverters can be used to convert parallel resonance to a series resonance characteristic.
- A familiar impedance inverter is the $\lambda/4$ line.
- LC forms provide moderate bandwidth Z inversion.
- Capacitive T and π sections are for narrow band applications. Negative C or L is absorbed into resonator (cancels some positive C or L).



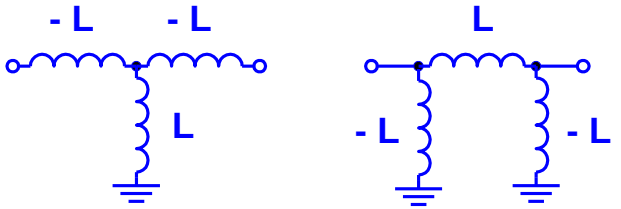
$$Z_0, \quad \theta = \frac{\lambda}{4}$$



$$Z_0 = \sqrt{\frac{L}{C}}, \quad \omega_0 = \frac{1}{\sqrt{LC}}$$

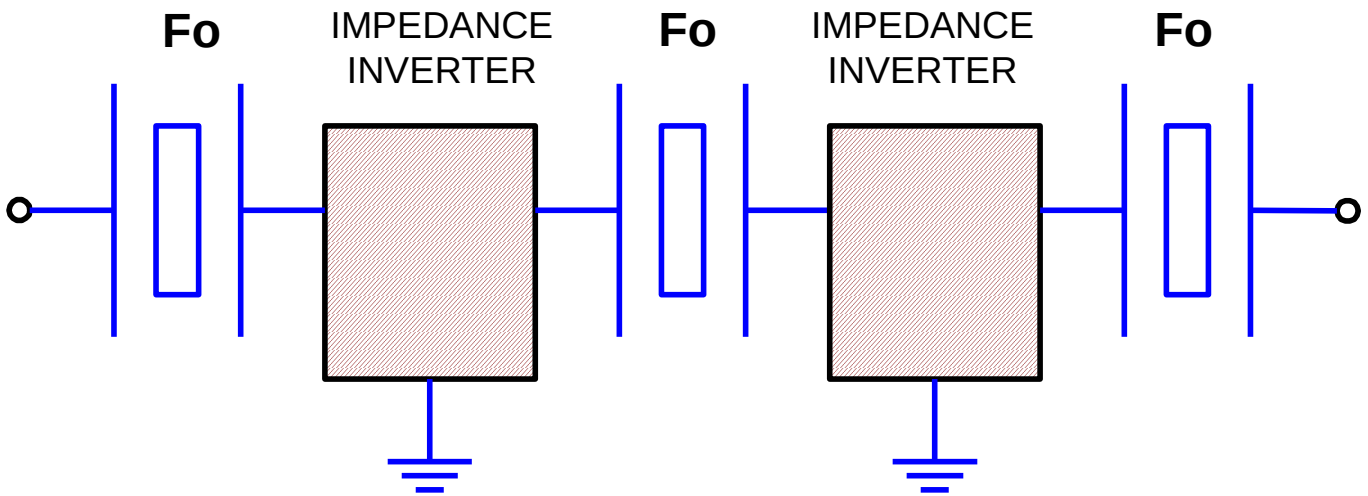


$$Z_0 = \frac{1}{\omega_0 C}$$



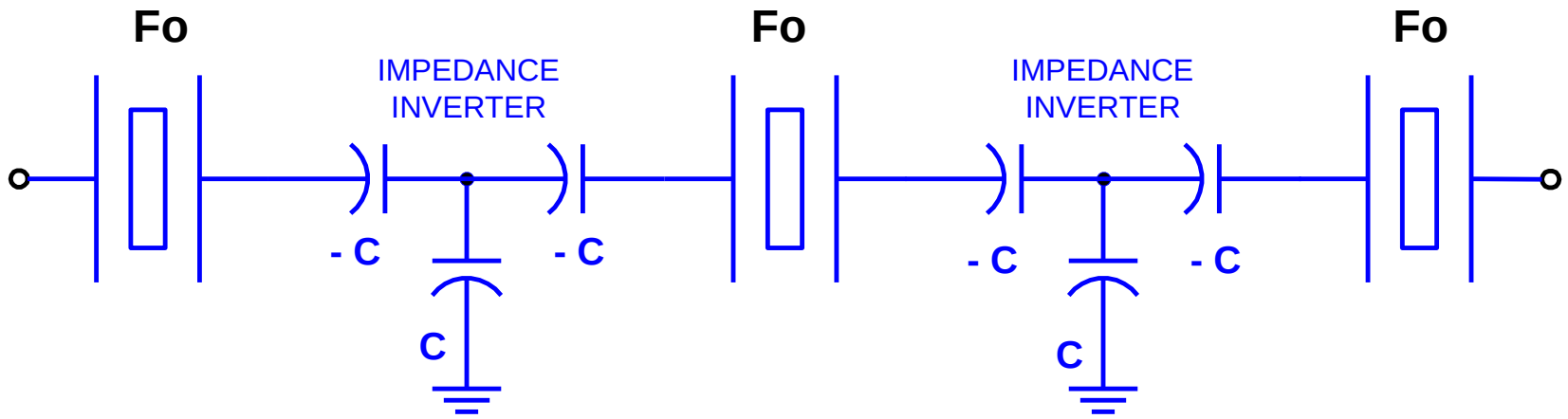
$$Z_0 = \omega_0 L$$

LADDER XTAL FILTER – THREE POLE



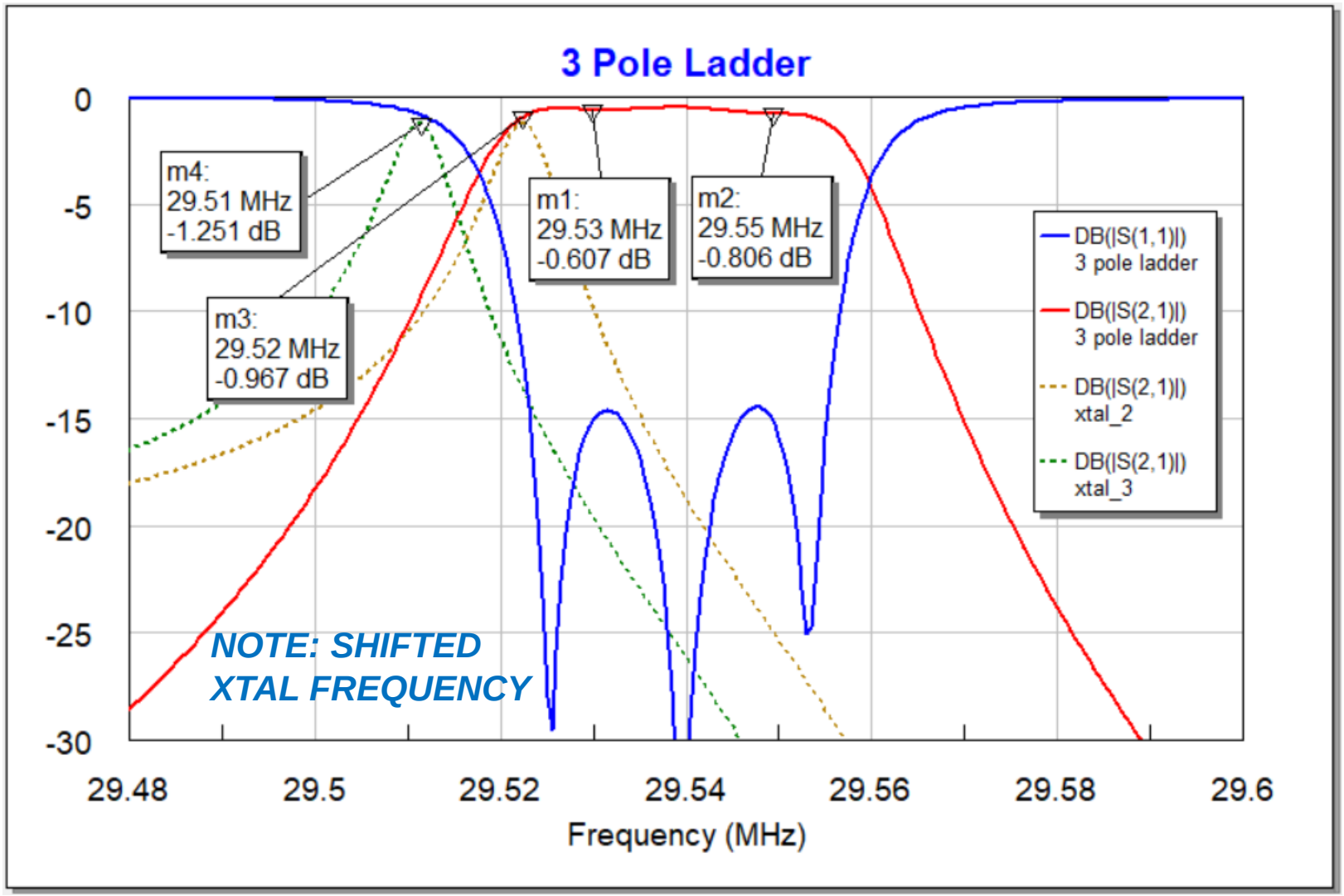
- Impedance inverters set inter-resonator coupling
- Port impedance is higher than 50 Ω
- All resonators are synchronously tuned to Fo

LADDER XTAL FILTER – THREE POLE

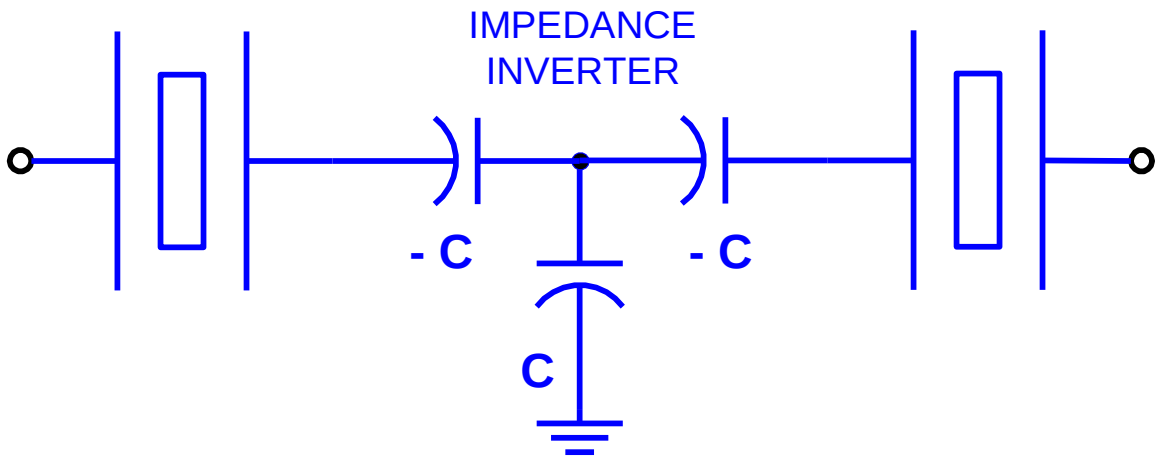


- A capacitive T can form an impedance inverter
- The series branches are negative C (inductive)
- A resonator in series with a negative C is equivalent to a resonator shifted down in frequency
- So the crystal and negative C branch can be replaced by a new lower frequency crystal
- The center crystal is shifted more than outer crystals

SIMULATED RESPONSE

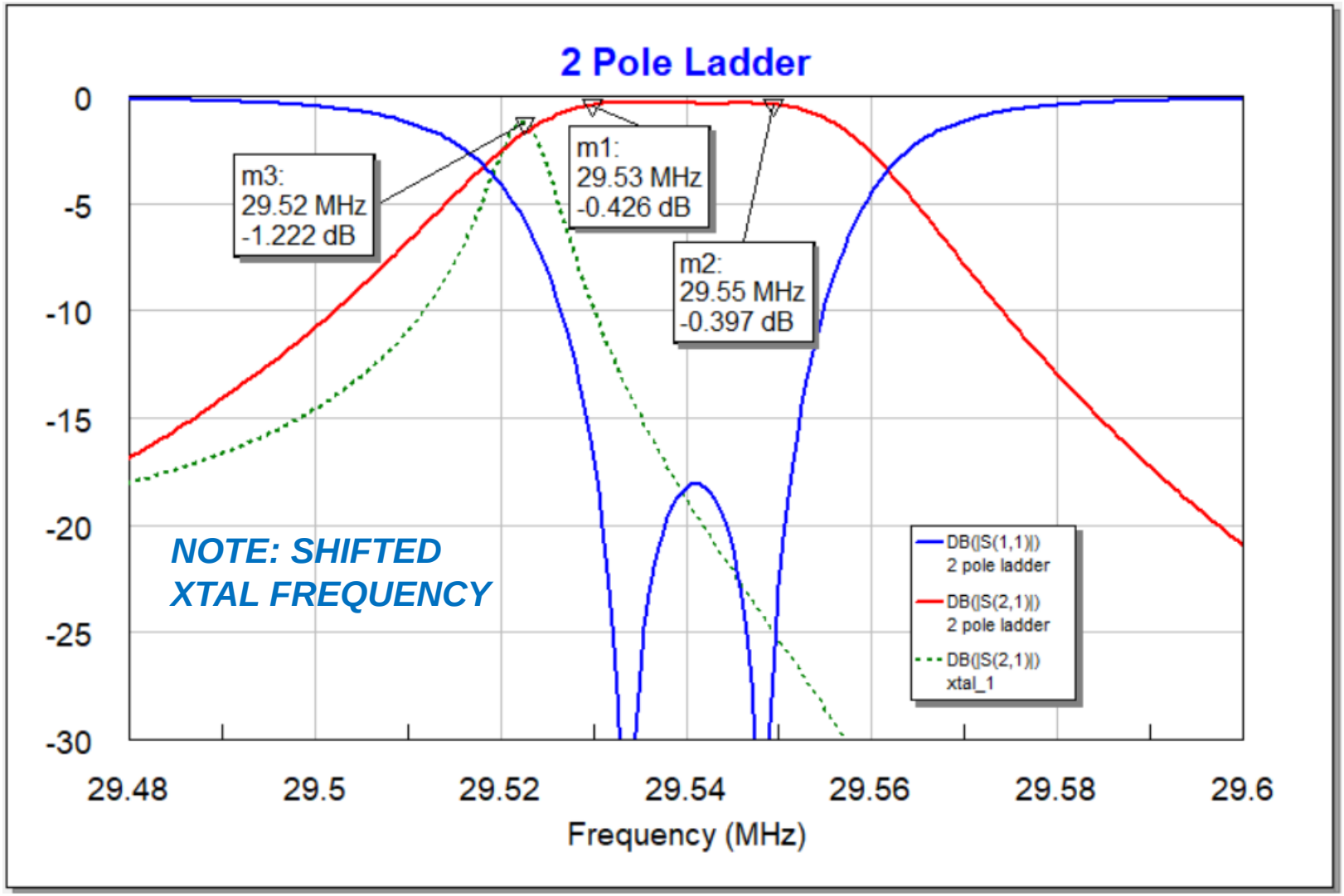


LADDER XTAL FILTER – TWO POLE

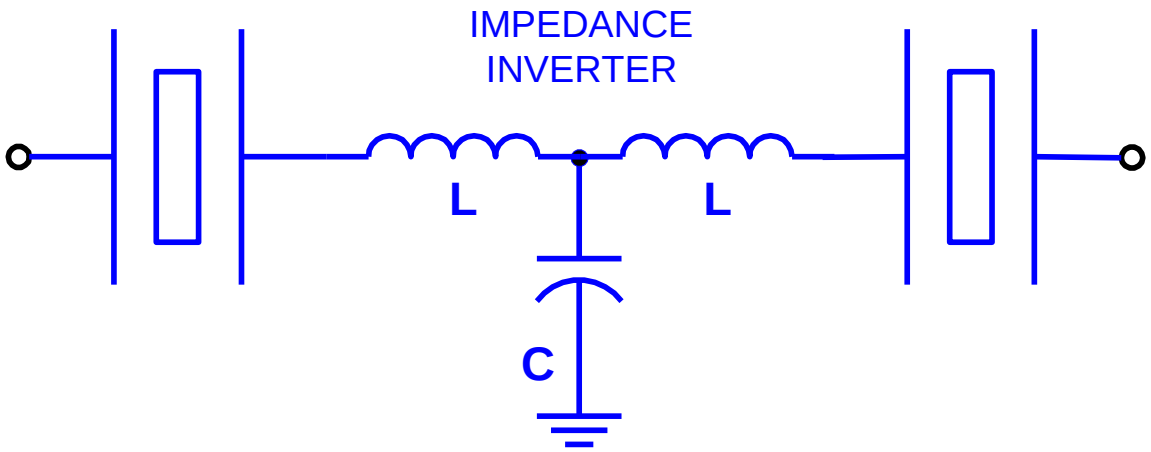


- A two resonator filter with a single shunt coupling capacitor would require crystals tuned slightly below the desired center operating frequency.
- Crystals can be all tuned to the center frequency if the impedance inverter can be fully realized external to the crystal (no neg cap absorption).

SIMULATED RESPONSE

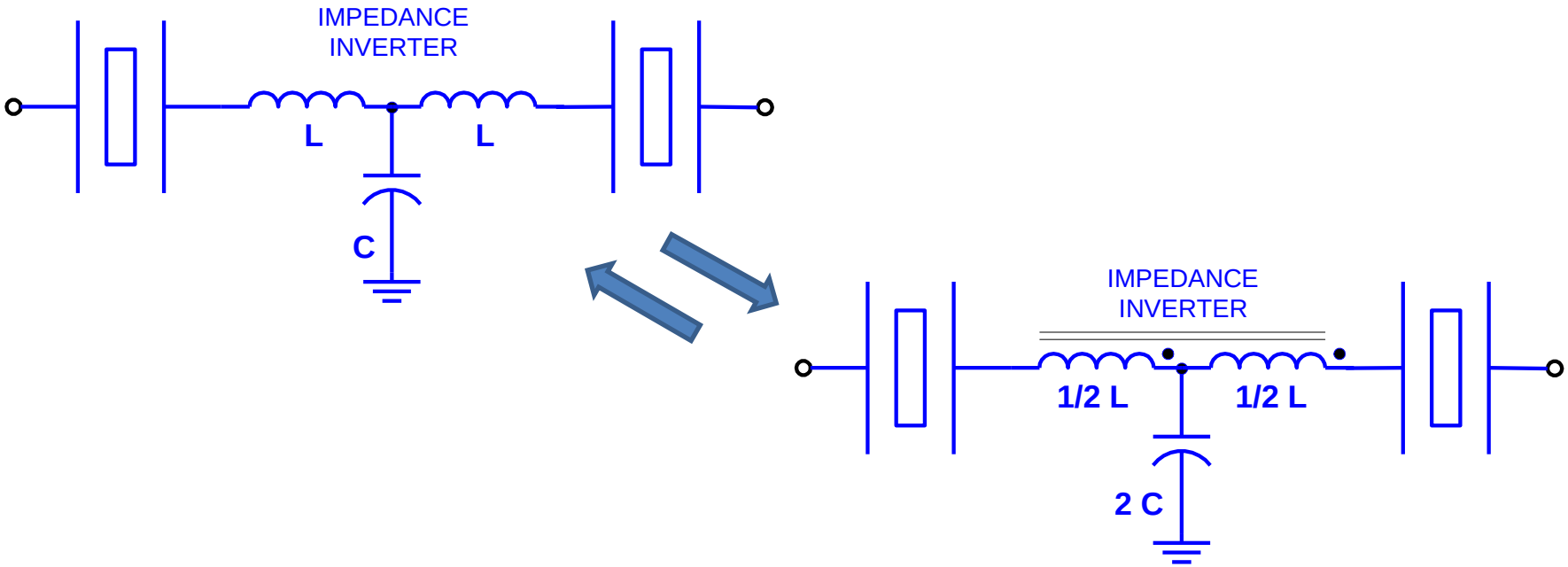


LADDER TWO POLE WITH REALIZABLE INVERTER



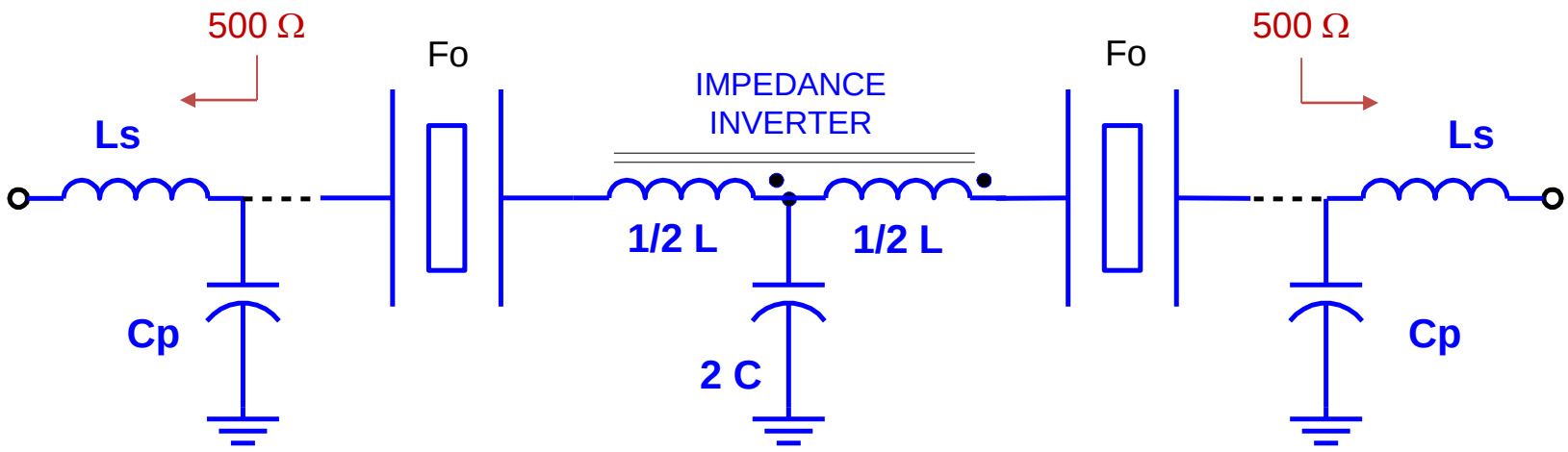
- An LC impedance inverter can be provided with all positive valued elements as shown above
- All crystal resonators should be tuned at the desired center frequency
- This makes crystal selection easier

NEW IMPEDANCE INVERTER



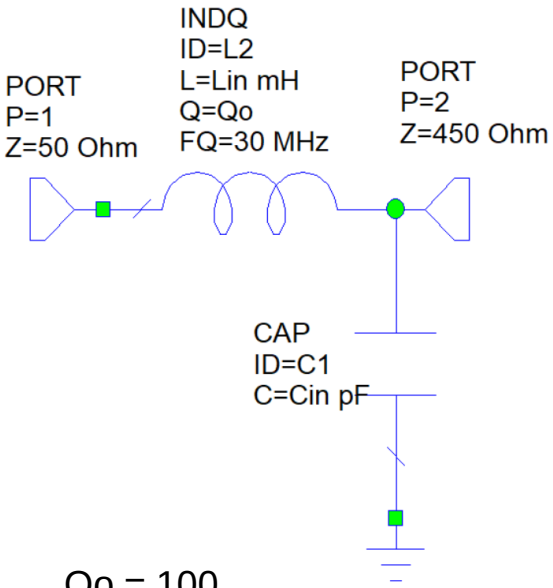
- An impedance inverter equivalent to the 2 inductor and shunt cap form can be realized with a center tapped (coupled) inductor and single shunt cap.
- This equivalence is showed above

LADDER XTAL FILTER WITH LC MATCH AT PORTS

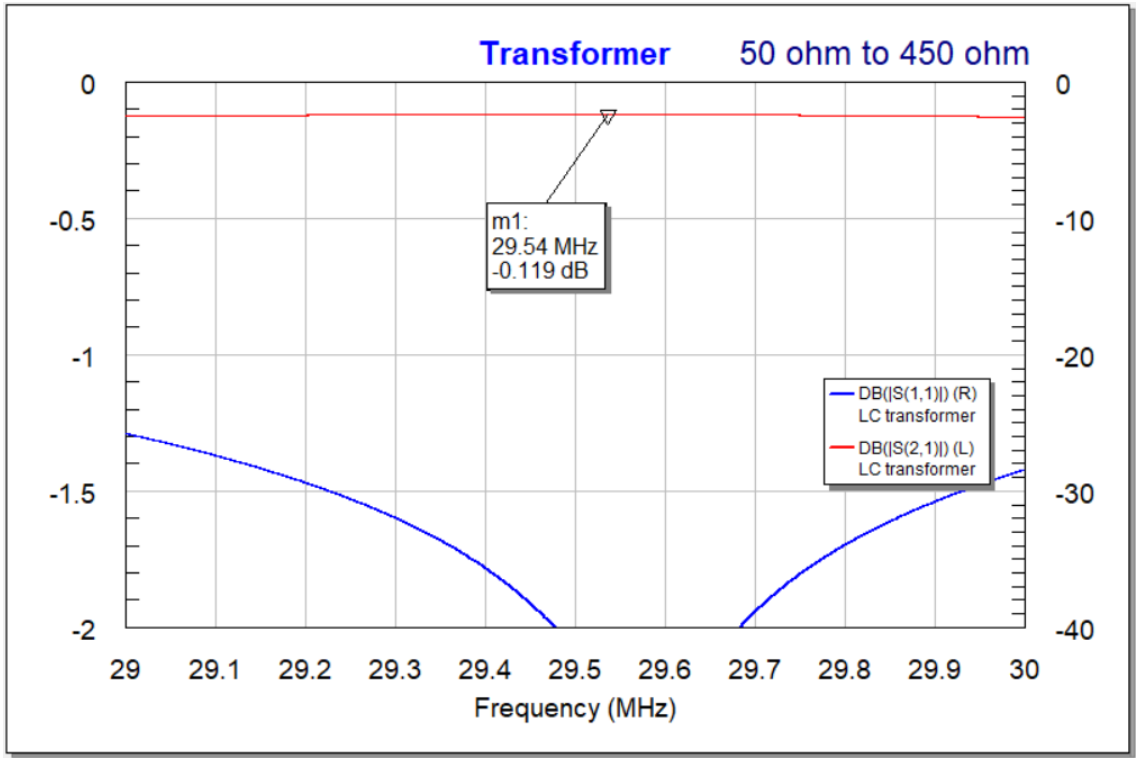


- The complete 2 resonator filter structure with 50 ohm ports is shown above
- All crystal resonators are tuned to the desired center frequency
- Ls and Cp provide port impedance transformation to approximately 500 Ω

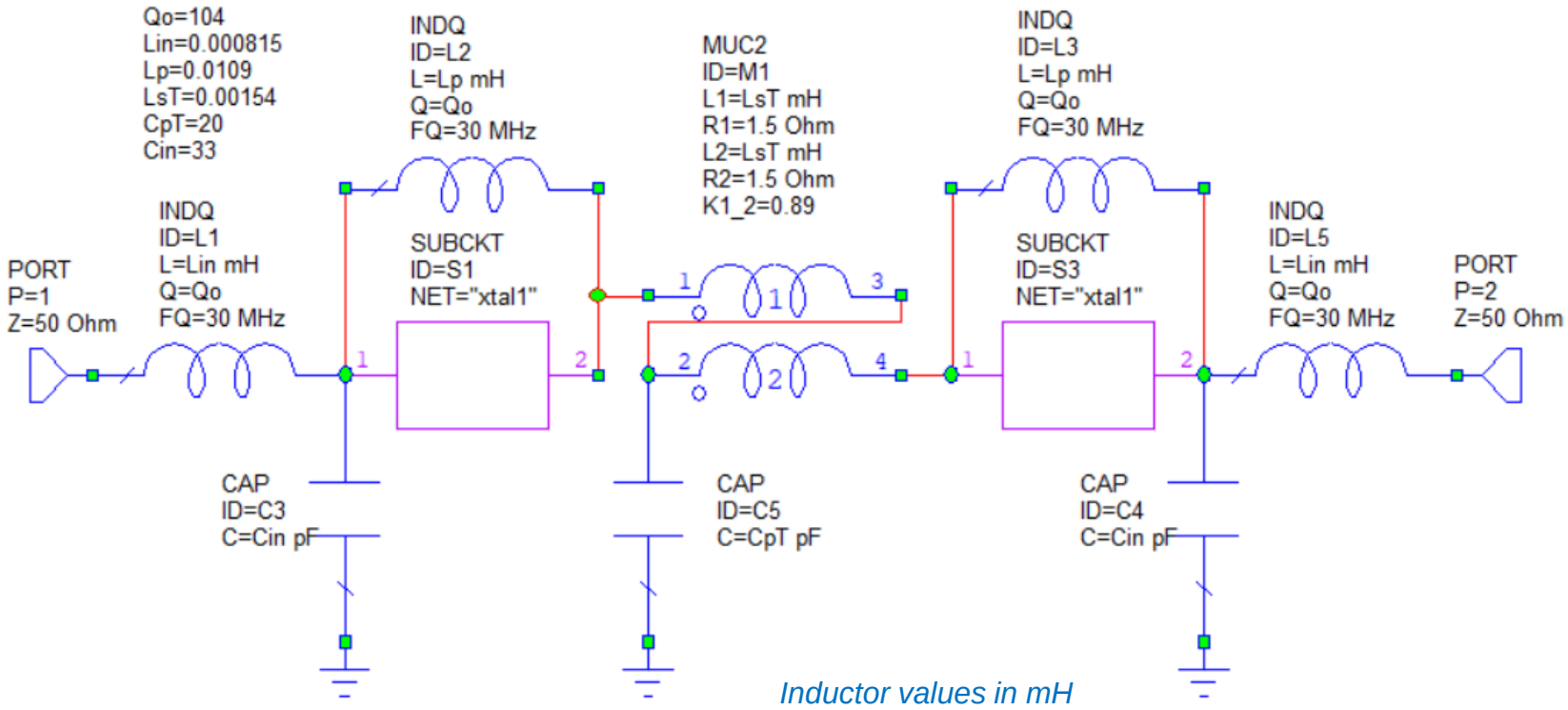
LC TRANSFORMER CIRCUIT



Qo = 100
Lin = 0.755 uH
Cin = 34.5 pF

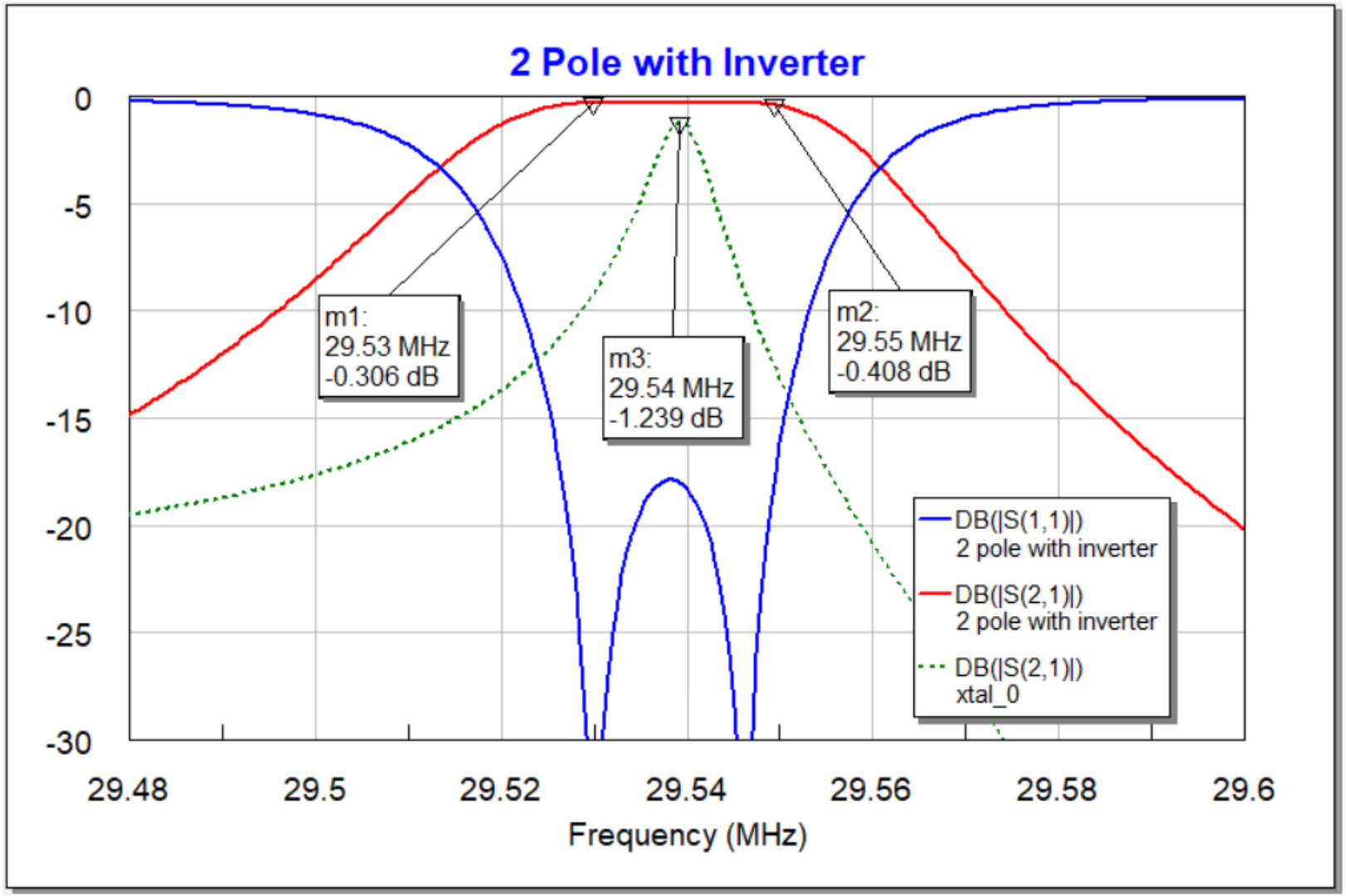


SIMULATION CIRCUIT - COMPLETED FILTER

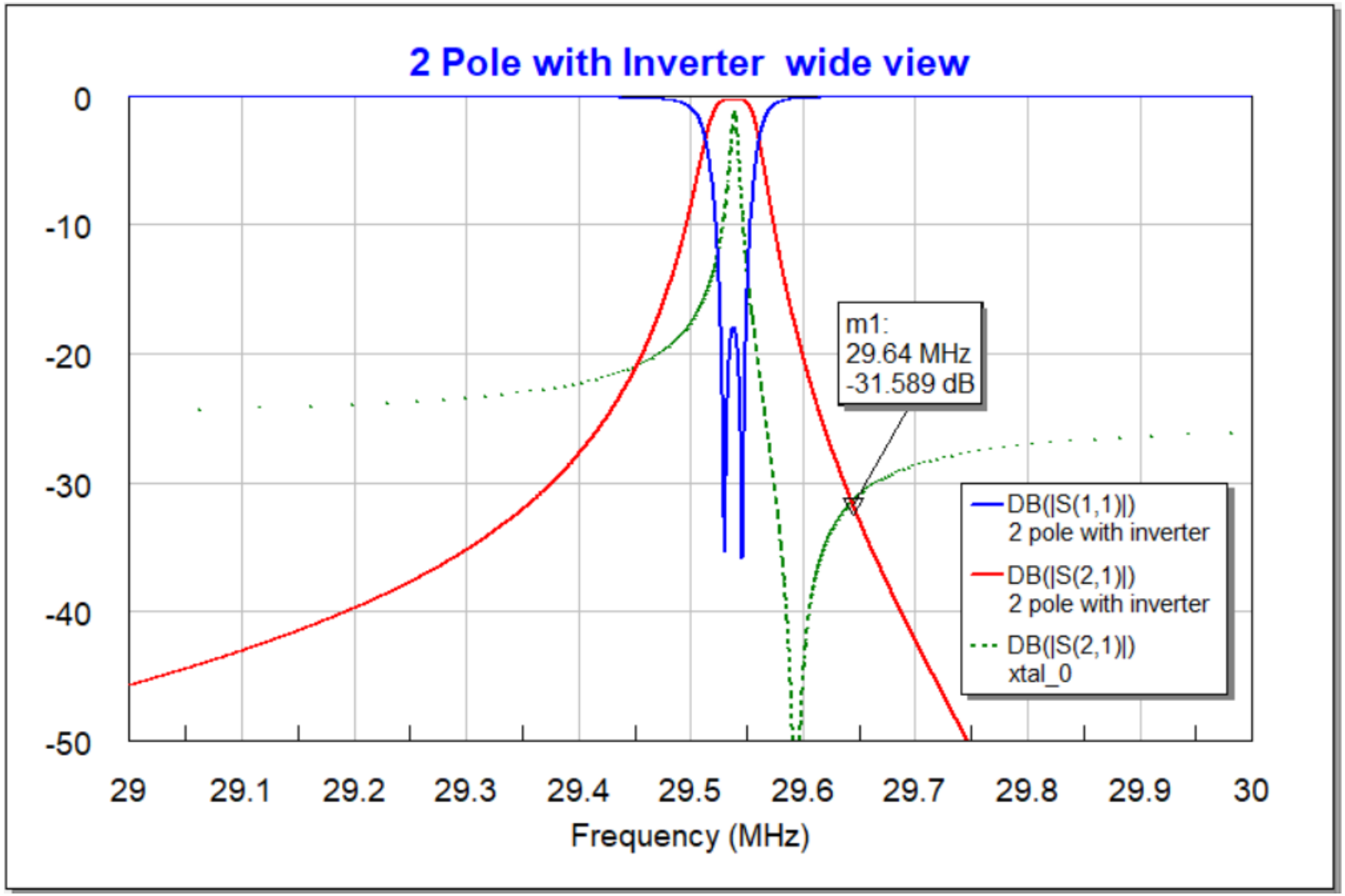


- Crystal parasitic parallel capacitances are partially resonated with parallel inductors L2 and L3 (10.9 uH)
- This will shift the parallel resonance up and away from the filter passband

SIMULATED RESPONSE



SIMULATED RESPONSE



SUMMARY

- Crystal filter provides an extremely narrow filter
- Solution is 0.07% BW
- TX isolation >30 dB
- New impedance inverter realized with tapped toroid inductor
- Use of external impedance inverters allows ALL crystals to be resonant at the center frequency
- Parallel resonance due to case and internal contacts is shifted away from passband with a large parallel inductor (approx. 10.9 uH).