EE172 Project: 5^{th} Order Elliptic Band-Pass Filter

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***Abstract* — A 5th order elliptical band-pass filter is designed, built and characterized in this project using a Genesys Eagleware tool. Two prototypes are built and measured so that the simulated and measured results are compared. The resultant graphs are properly plotted and presented in this paper.**

I. Introduction

An **elliptic filter,** sometimes also called as a **Cauer filter** or a **Zolotarev filter** , is a signal processing filter well known for its steepest transition between passband and the stopband compared with other filter types such as Bessel, Butterworth and Chebyshev. The following table clearly shows the comparison between the behaviors of all the famous filter functions known to the mankind.

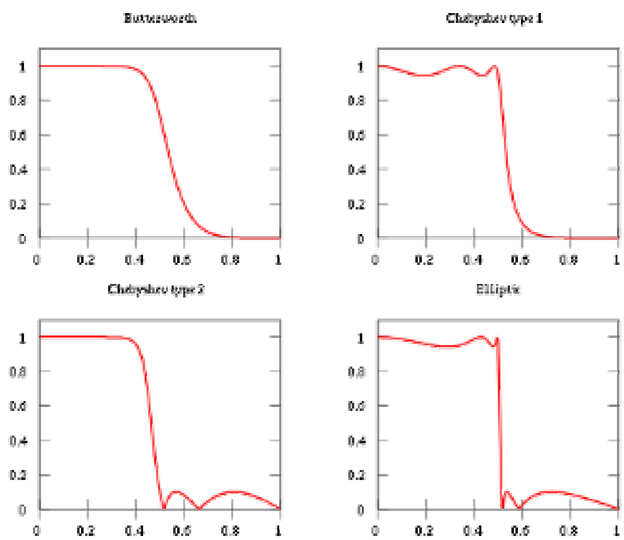

Figure (1) *Comparison of Filter Types* [2]

II. Design Methodology and Simulations

A. *Specifications and Filter Topology*

Here are the specifications set for the bandpass filter.

- The Center Frequency: 120 MHz
- BW: 40 MHz (from 100 MHz to 140 MHz)
- S11 & S22: <-15 dB
- Stopband Rejection: <-40 dB

To achieve those specifications, the Butterworth will need minimum order of 11, the Chebychev will need minimum order of 6 while the Elliptic only need 5 [3]. Even though, the Elliptic filters possess a weakness of having the most nonlinear phase response over their pass band, it yields the least order compared with others. Thus, the elliptic topology becomes my first choice for this project. The table from the Zverev book [4] is used as references as shown in figure (2).

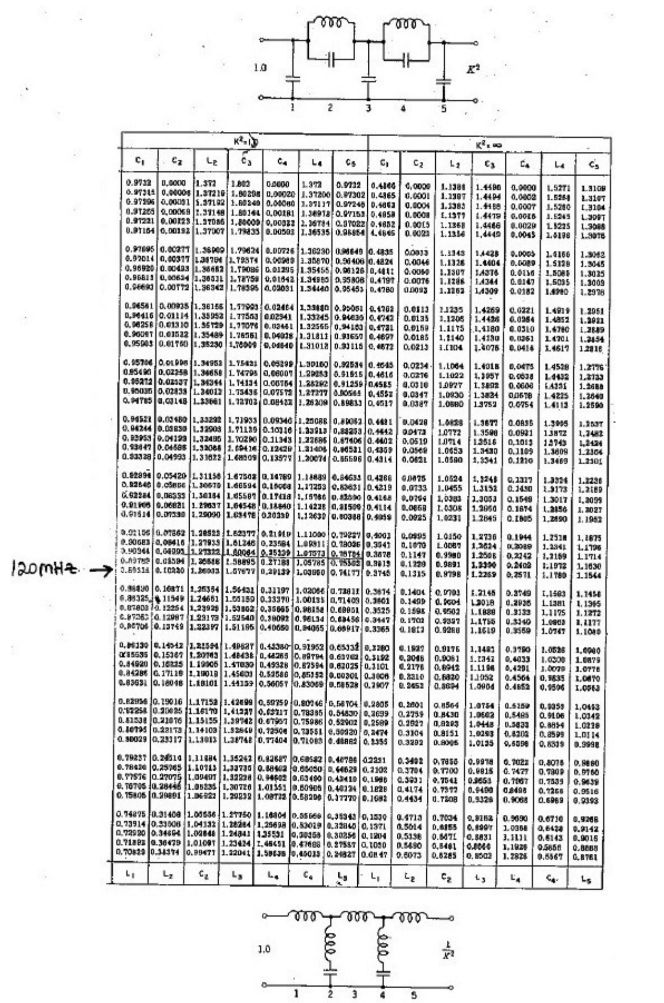

Figure (2) *ZVEREV Elliptic Filter Functions Table* [4]

Those values are used in Excel sheet as shown below to calculate lumped elements values to be applied in filter building.

	Lowpass Prototype	Series Arm		Series Arm							
		Parallel L (H)		Parallel L (H)			Ro (ohms)	f1(MHz)	f2(MHz)	wo(Mradians)	Qbw
	Shunt C (F)	Parallel C (F)	Shunt C (F)	Parallel C (F)	Shunt C (F)		50	93	160	766	1.820651
		1.27322		1.07573							
	0.90244	0.08993	1.60084	0.25339	0.76784						
	Bandpass	Series Arm		Series Arm							
	Shunt Resonator	Series Arm of Series Arm	Shunt Resonator	Series Arm of Series Arm	Shunt Resonator						
	L(nH)	L(nH)	L(nH)	L(nH)	L(nH)						
	C(pF)	C(pF)	C(pF)	C(pF)	C(pF)						
	39.70	151.22	22.38	127.77	46.67						
	42.87	11.26	76.05	13.32	36.48						
		Parallel Arm of Series Arm		Parallel Arm of Series Arm							
		L(nH)		L(nH)							
		C(pF)		C(pF)							
		398.43		141.41							
		4.27		12.04							
	Lowpass Prototype	Shunt Arm		Shunt Arm							
		Series L (H)*		Series L (H)*							
	Series L(H)	Series C (F)*	Series L(H)	Series C (F)*	Series L(H)						
		0.08993		0.25339							
	0.90244	1.27322	1.60084	1.07573	0.76784						
	Bandpass	Shunt Arm		Shunt Arm							
		Series LC of Shunt Arm		Series LC of Shunt Arm							
		L(nH)		L(nH)							
	Series LC	C(pF)	Series LC	C(pF)	Series LC						
	L(nH) L2	10.68	L(nH)	30.10	L(nH) L7						
	C(pF) C2	159.37	C(pF)	56.56	C(pF) C7						
L1	107.18	Parallel LC of Shunt Arm	190.14	Parallel LC of Shunt Arm	91.20	L5					
C1	15.88	L(nH)	8.95	L(nH)	18.67	C5					
		C(pF)	L4, C4	C(pF)							
	L3	28.14		33.31	L6						
	C3	60.49		51.11	C6						

Figure (3) *Lumped Values Calculations in Excel*

B. *Simulations*

First the calculated values were used in the Genesys Eagleware software to simulate the filter response as seen in figure (4).

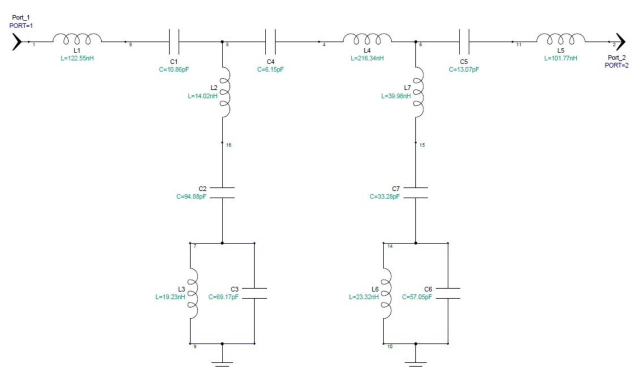

Figure (4) *Lumped Elements Schematic*

The resultant gain (S21), the input return loss (S11) and the output return loss (S22) graphs are plotted in figure (5).

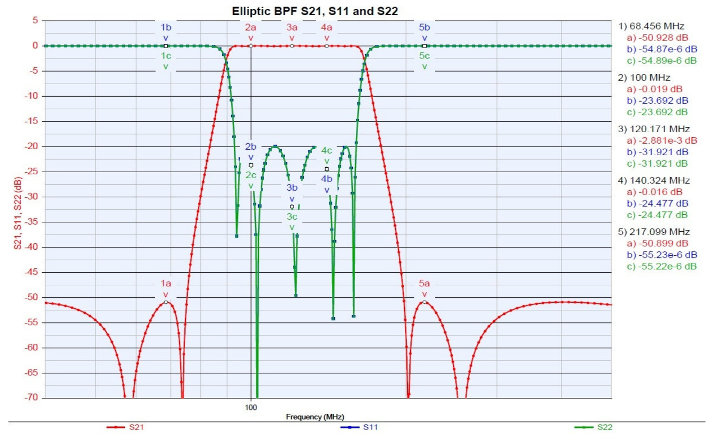

Figure (5) Simulated S21, S11 and S22 graphs

However, we need to see how the filter will behave using the real lumped element values with low Qs such as Q of 500 for the capacitor and Q of 40 for the inductors including their lumped parasitic values as depicted in the following schematic.

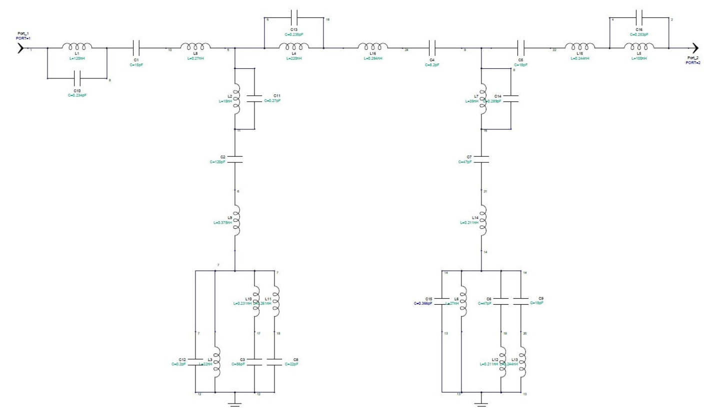

Figure (6) *Elliptic Filter Schematic with real Lumped Values*

The final simulation results of S21, S11and S22 are matching with specifications as seen in figure (7).

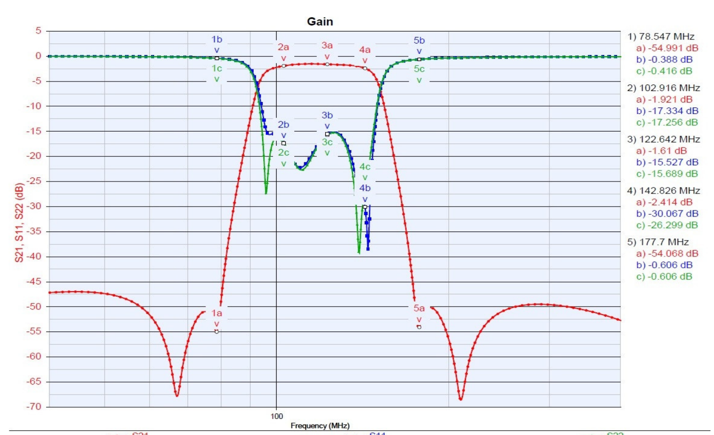

Figure (7) *Final Simulation S21, S11 and S22 results*

III. PROTOTYPE, MEASUREMENTS AND RESULTS

Now, it is ready to build a filter prototype and see if it behaves like as in simulations. Here are the final values for the inductors and capacitors used in building the first prototype.

- L1 : 100nH
- L2 : 12nH
- L3 : 27nH
- L4 : 220nH
- L5 : 100nH
- L6 : 33nH
- L7 : 39nH
- C1 : 18pF
- C2 : 120pF
- C3 : 56pF
- C4 : 8.2pF
- C5 : 18pF
- C6 : 56pF
- C7 : 47pF
- C8 : 10pF

The first prototype was built on a copper plane on a FR-4 substrate as shown in figure (8) below.

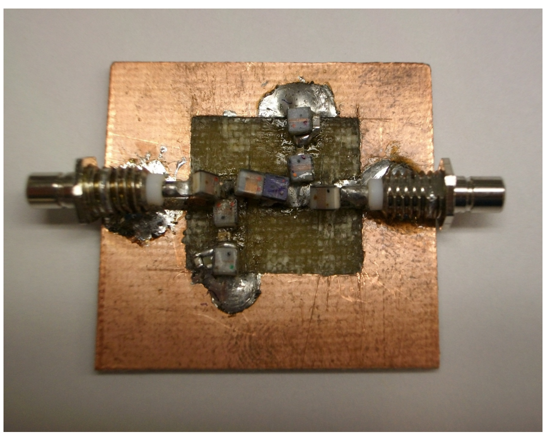

Figure (8) *First Elliptic Filer Prototype*

The following figure shows the measured S21 of the first prototype filter. The rejection between the passband and stopband is only 20dB down unlike 40dB in simulations.

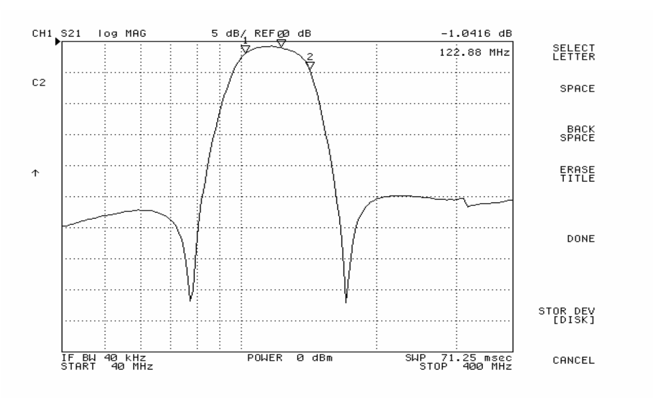

Figure (9) *Measured S21 result of first prototype filter*

IV. PROTOTYPE WITH A 50 Ω TRANSMISSION LINE

When I tried to fix the first prototype, some lumped elements were accidentally damaged and the results gone worse.
So, I tried to build another prototype and see it better results will be achieved. I think the first failure was mainly because of parasitic effects on the stacked components. So, I decided to use the transmission line in the filter. The characteristics of the FR-4 substrate can be seen in figure (10).

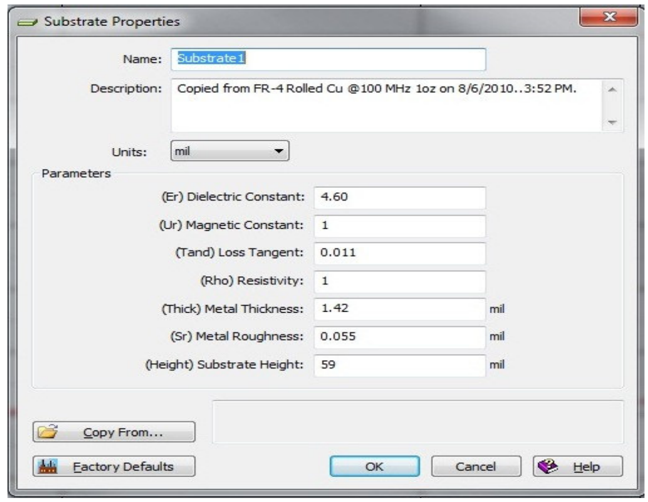

Figure (10) *Dielectric constant and height of substrate*

Putting those values in the online tool [7] for the frequency of 120MHz gives the 50 Ω Transmission Line width to be around 110 Mils (2.725mm) as seen in the below figure (11).

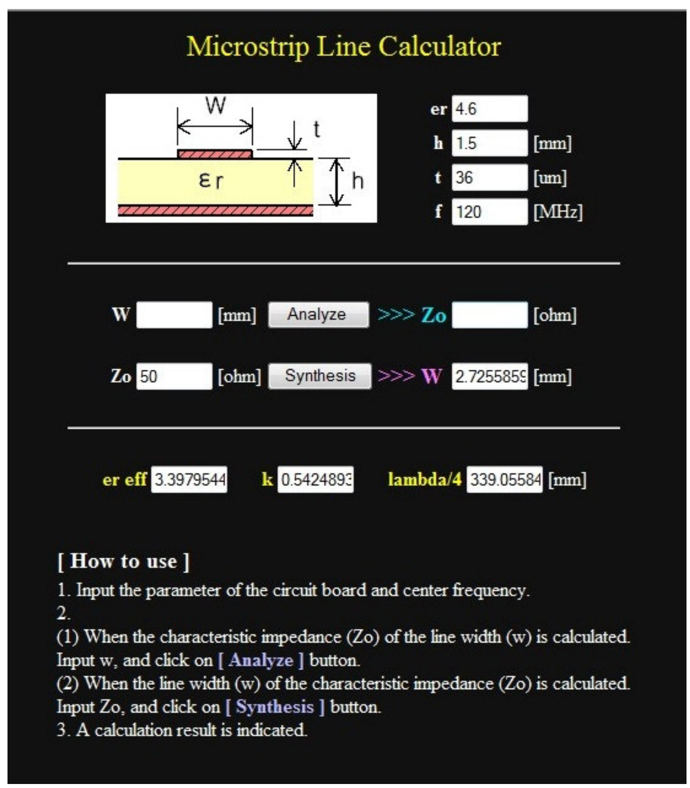

Figure (11) *Online Transmission Line width Tool*

The second prototype filter is built on a transmission line using the whole copper plane as the ground as seen in figure (12).

Figure (12) *Secondly-built Prototype Filter*

The filter was tested using a network analyzer as in fig. (13).

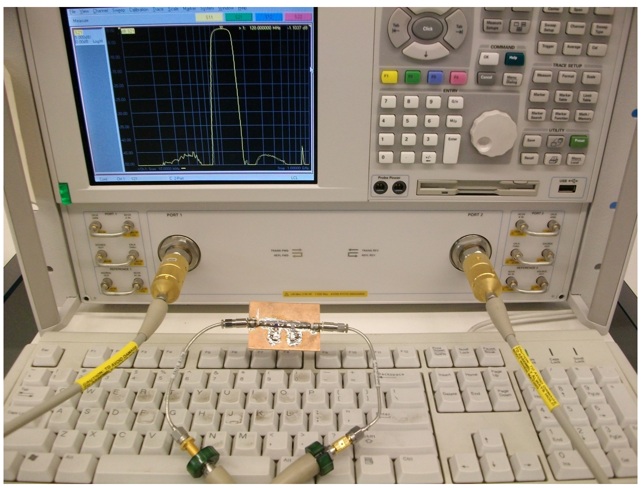

Figure (13) *Network Analyzer Test Setup*

The measured S21, S11 and S22 are pretty good compared with the first prototype as shown in figures (14), (15) and (16).

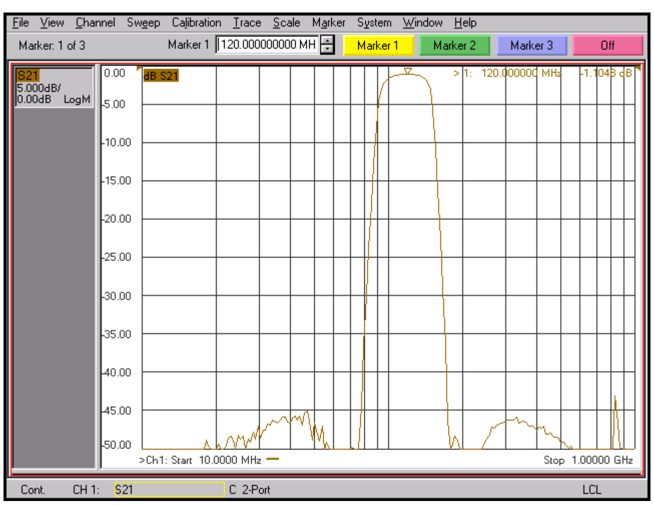

Figure (14) *Final Measured S21*

Figure (15) *Final Measured S11*

Figure (16) *Final Measured S22*

V. COMPARISONS AND DISCUSSION

The measured Gain (S21), the Input Return Loss (S11) and the Output Return Loss (S22) of the simulation and measurement graphs are compared in the figures (17), (18) and (19).

In figure (17), the measured plot closely resembles the simulation and it is at least 40 dB down between the passband and stopband as specified. In fig. (18), The S11 gave the similar results with at least 18dB down in the whole bandwidth (100 MHz to 140 MHz). The S22 also gives a pretty good result although it is only 13 dB down at 100 MHz in fig. (19).

Overall, the results show the second prototype is a decent 5th order elliptical filter meeting all specifications defined above.

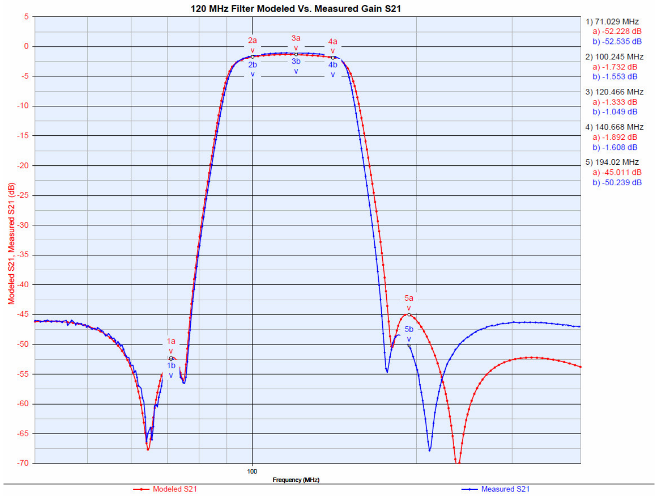

Figure (17) *Simulated (Red) Vs. Measured (Blue) S21 Plots*

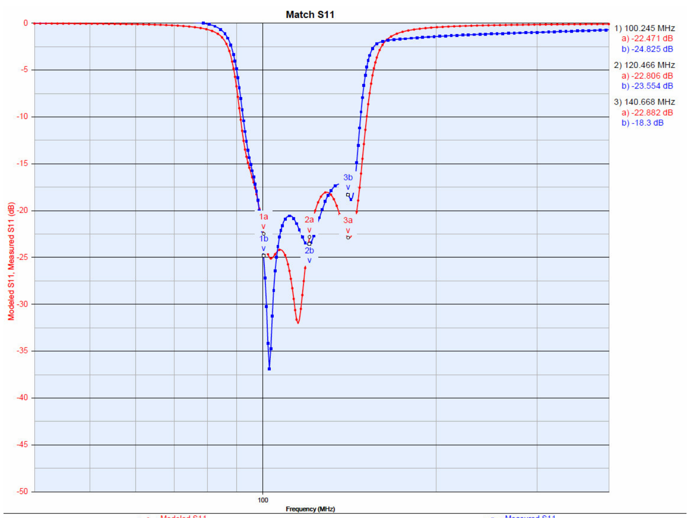

Figure (18) *Simulated (Red) Vs. Measured (Blue) S11 Plots*

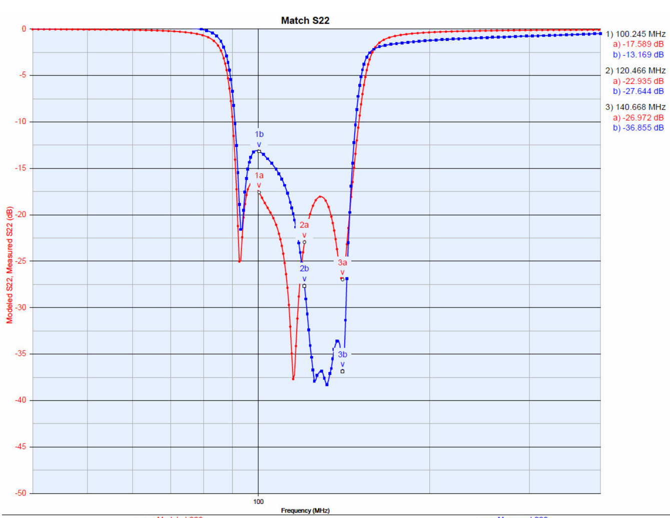

Figure (19) *Simulated (Red) Vs. Measured (Blue) S22 Plots*

VI. Conclusion

A 5th order elliptical band-pass filter was characterized and built by using Genesys Eagleware RF simulation software. Even though the first-built filter run a little short of meeting all the required specifications, the measured results of the secondly-built filter showed that the input and output return losses, S11 and S22, are pretty matched and also the gain S21 is well met with the simulation graphs generated. Thus, a 5th order elliptic band-pass filter is successfully designed, simulated, built, measured, and all the results are properly plotted and compared in this report.

Acknowledgment

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References

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