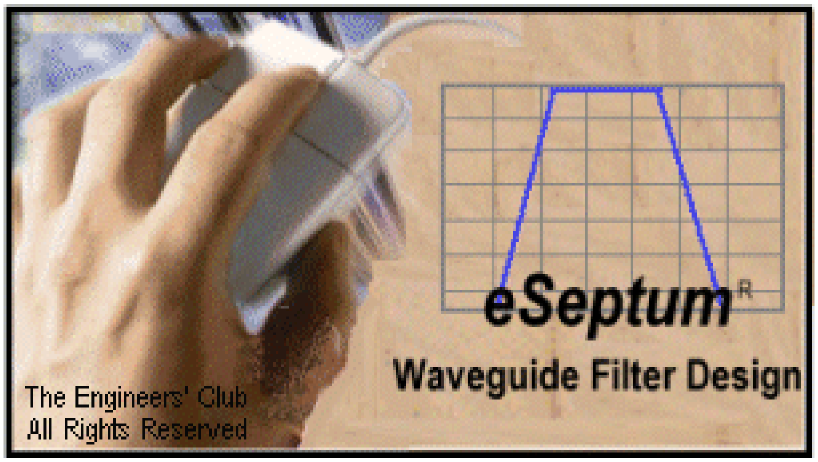
eSeptum™



Tutorial

April 2, 1999 eSeptum.doc

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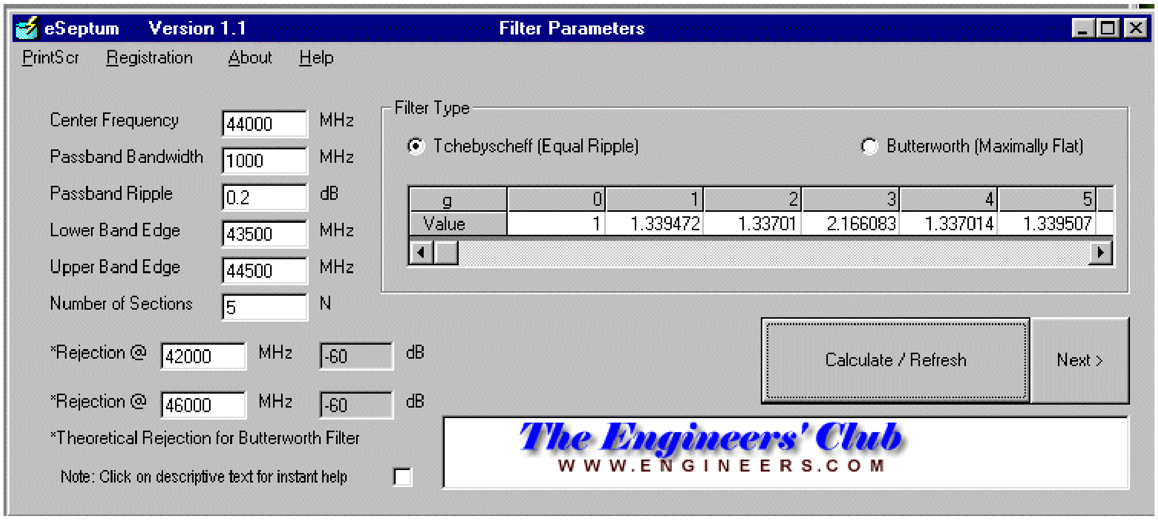
This tutorial walks you through a complete filter design. The design is optimized for manufacturability and low cost. Additionally, the tutorial gives you a design methodology easily adapted to your future designs at any frequency band.

DEFINE THE FILTER REQUIREMENT:

A receive filter must be designed for a digital radio transceiver. The transmitter overpowers the receiver by 25 dB. The receiver operates at 44,000 MHz with a bandwidth of +/-500MHz. The transmitter tunes from 41,000 MHz to 42000 MHz. The Local Oscillator leakage from the receiver is at 46GHz and is -35 dBm, There are some receiver spurious at 60 GHz; the level is -40dBm. ETSI specifications requires all out of band transmitted spurious to be -60 dBm. This requires at least 20 dB of filter rejection.

Design Parameter	Design Goals	Comments
Center Frequency	44,000 MHz	
Bandwidth	+/-500 MHz	
Ripple	0.2dB	0.25dB acceptable
Rejection 41 to 42 GHz	30 db (Minimum)	
Rejection 46 GHz	30 dB (Minimum)	ETSI Spec
Rejection 55 to 65 GHz	20 dB (Minimum)	ESTI
Temperature Range	-30, +70 Degrees C.	
Materials	Aluminum Housing	For Low cost
Machining Tolerance	+/-0.001 inches	"A" dim.of guide
Housing Plating	50 uinches Nickel	
Septum	BeCu 0.004" thick	Nickel Flash

Filter Parameters   SCREEN ONE

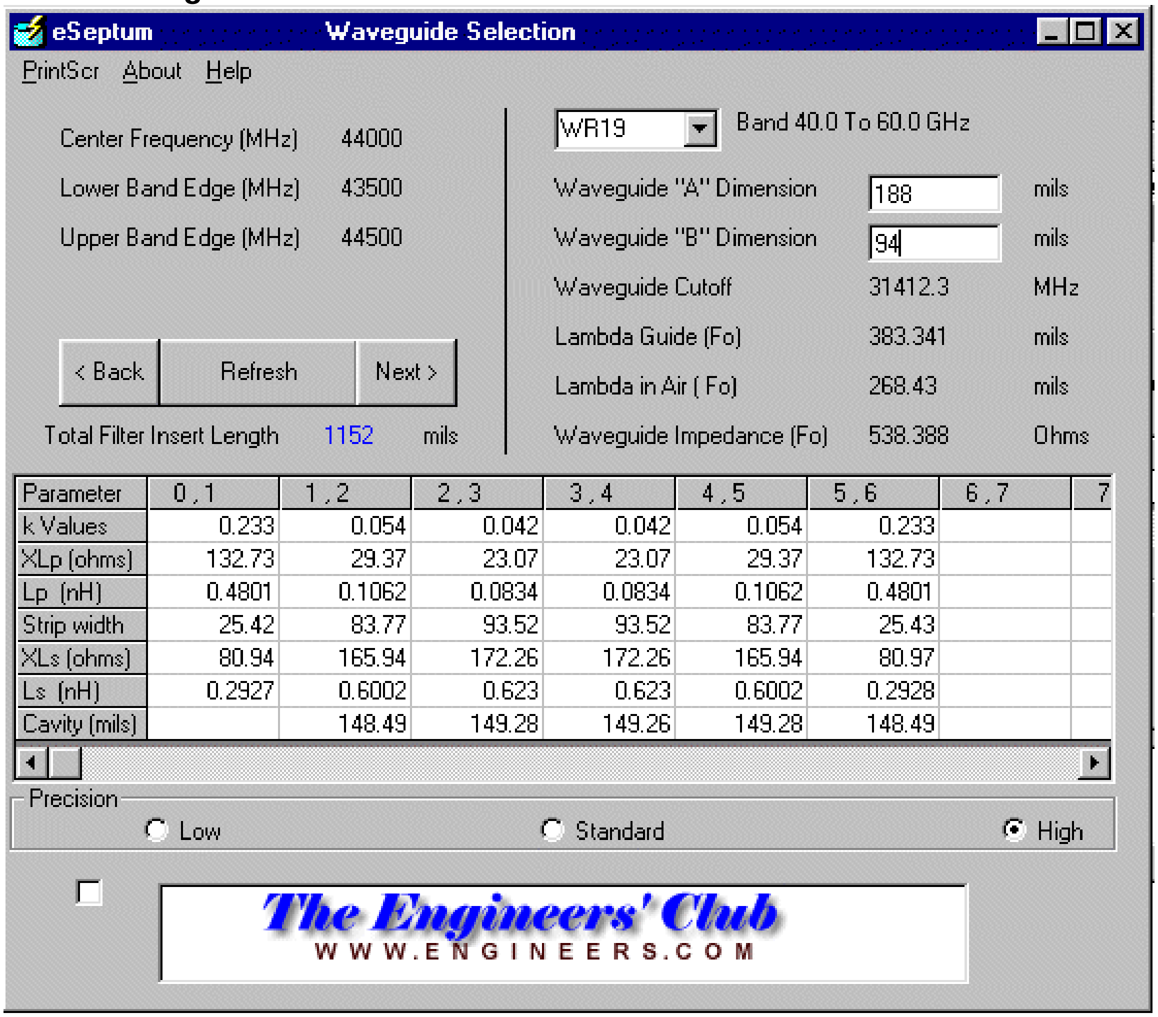


SETTING UP THE FILTERS PARAMETERS

1. Default Filter Type: Tchebyscheff
2. CENTER FREQUENCY: **ENTER** 44,000 MHz
3. Bandwidth : **ENTER** 1,000 MHz
4. Ripple: **ENTER** 0.2 dB
5. Lower Band Edge: **DOUBLE-CLICK** for AUTOFIL
6. Upper Band Edge: **DOUBLE-CLICK** for AUTOFIL
7. Rejection (1): **ENTER** 42,000 MHz
8. Rejection (2): **ENTER** 46,000 MHz
9. Experiment with "N" value to find rejection values of greater than 30dB yield about 36dB). **Add 2 more sections (N=5)** to increase yields in manufacturing and allow for temperature drift and tolerance. This will result in **rejections of 60 dB** at BOTH rejection frequencies.
10. **CLICK** Calculate/Refresh to update "g values" to current settings.
11. **CLICK** Next > for the "WAVEGUIDE SELECTION SCREEN"

Note: CLICK the CHECK BOX next to the LOGO if you want an area to TITLE your page (useful if printing the screen).

Waveguide Selection SCREEN TWO



SELECTING THE APPROPRIATE WAVEGUIDE BAND FOR YOUR DESIGN

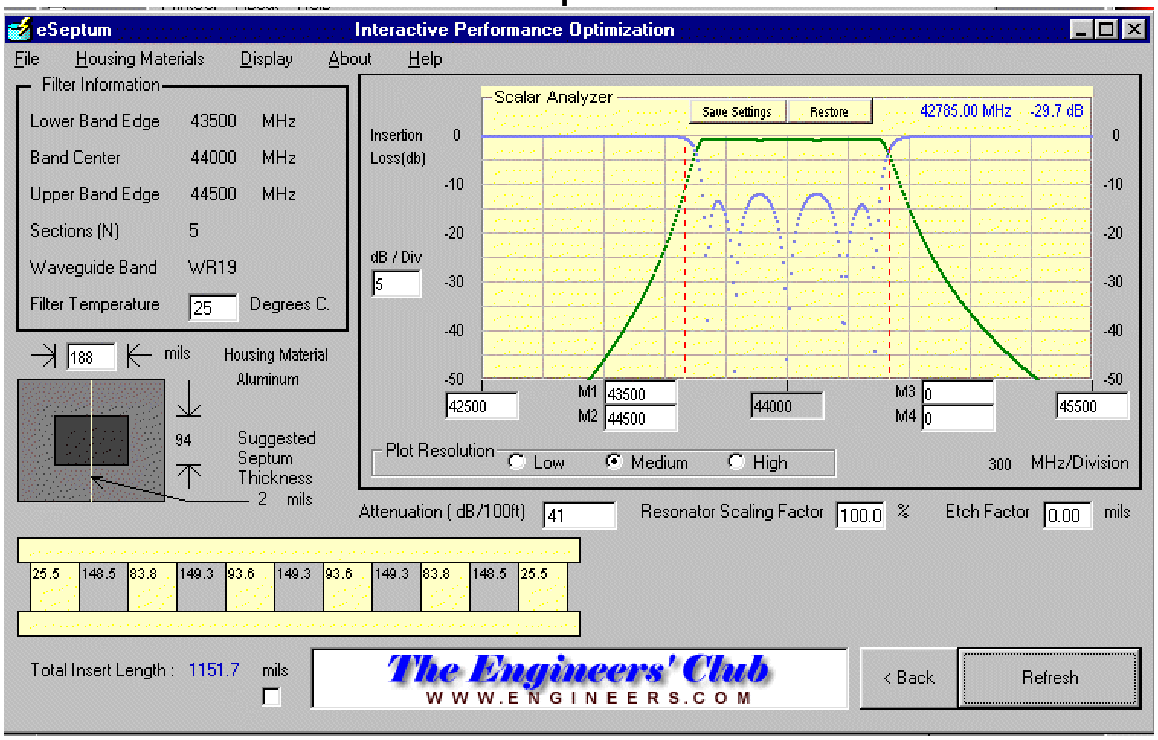
As you can see, *eSeptum* has already done the work for you. The waveguide has been selected as WR19 and the k parameters quickly calculated.

The mechanical dimensions of the filter are shown on line 4 of the matrix (Strip Width) and Line 7 of the matrix (Cavity). The total insert length is also shown (in blue) as 1152 mils. The total length is the summation of all the Widths and all the Cavities. Note that you have 5 cavities (resonators) since you requested an N=5 filter design.

The eSeptum **DEMO Version** is **locked to WR19** Waveguide. With the registered version, you could try your design with WR22 or WR28 Waveguide as well. For this case WR19 is, indeed, the best choice for the filter design.

CLICK NEXT> for "Interactive Performance Optimization, Screen Three.

Interactive Performance Optimization SCREEN THREE



FILTER PERFORMANCE BEFORE ANY OPTIMIZATION

PRESS <u>"REFRESH"</u> to plot filter performance using data from the "Waveguide Selection", Screen Two.

Let's take a minute to get familiar with the controls available:

Upper Left Corner - Filter Requirements from the first screen and test temperature

Left Center - End view of WR19 Waveguide showing a 2 mil thick septum "sandwiched" in the center of the waveguide. Data box for changing the "A" dimensions of the selected waveguide (The Demo Version is locked to 188 +/-8 mils).

Lower Left - Fully dimensioned layout of your filter insert. All dimensions shown can be changed and the performance effects viewed by pressing <u>"REFRESH"</u>

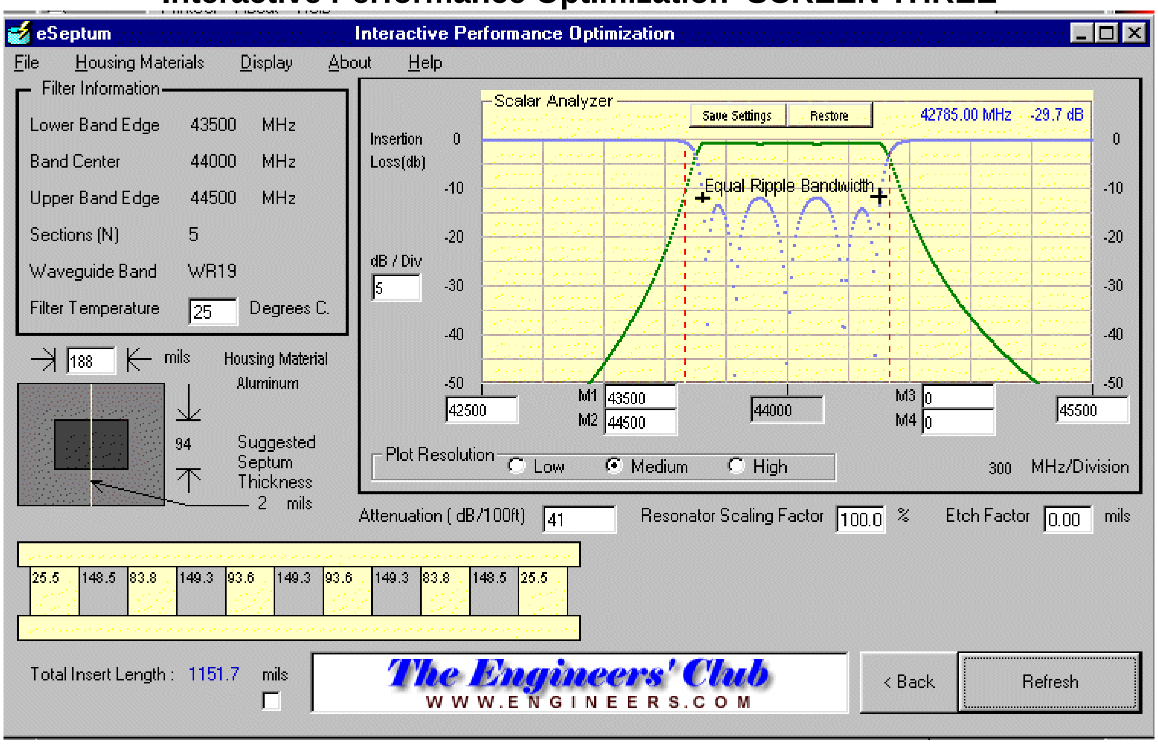
Upper Right - Scalar Analyzer. Preset for you by the frequencies you specified out on the first screen. You can change any scales by entering the new data and pressing <u>"REFRESH".</u> Please note the <u>"Save Settings"</u> and <u>"Restore"</u> buttons on the Analyzer. When the screen is set the way you want to view your design, press <u>"Save Setting"</u> so that you can <u>"Restore"</u> after you make modifications to your design.

Now verify your design for manufacturing margins and tolerance.

The MOUSEPOINTER TOOL (Crosshair) can be used as a “Delta F” measurement tool;

1. **POSITION** the mouse crosshair to the LEFT MOST EQUAL RIPPLE BAND EDGE (The point where return loss passes through -12.5dB on the left edge of the match display)
2. **CLICK** the LEFT MOUSE BUTTON to “ZERO” the Delta F Point at the LEFT EQUAL RIPPLE POINT of the filter.
3. **MOVE** the MOUSEPOINTER Crosshair to the RIGHT MOST EQUAL RIPPLE BAND EDGE and read the **“EQUAL RIPPLE BANDWIDTH”** of the filter.

Interactive Performance Optimization SCREEN THREE



TOTAL FILTER BANDWIDTH MEASUREMENT (Using Mousepointer tool)

The *DELTA F* reading is about 870 MHz, a **130 MHz shortfall** from your design requirement of 1000 MHz.

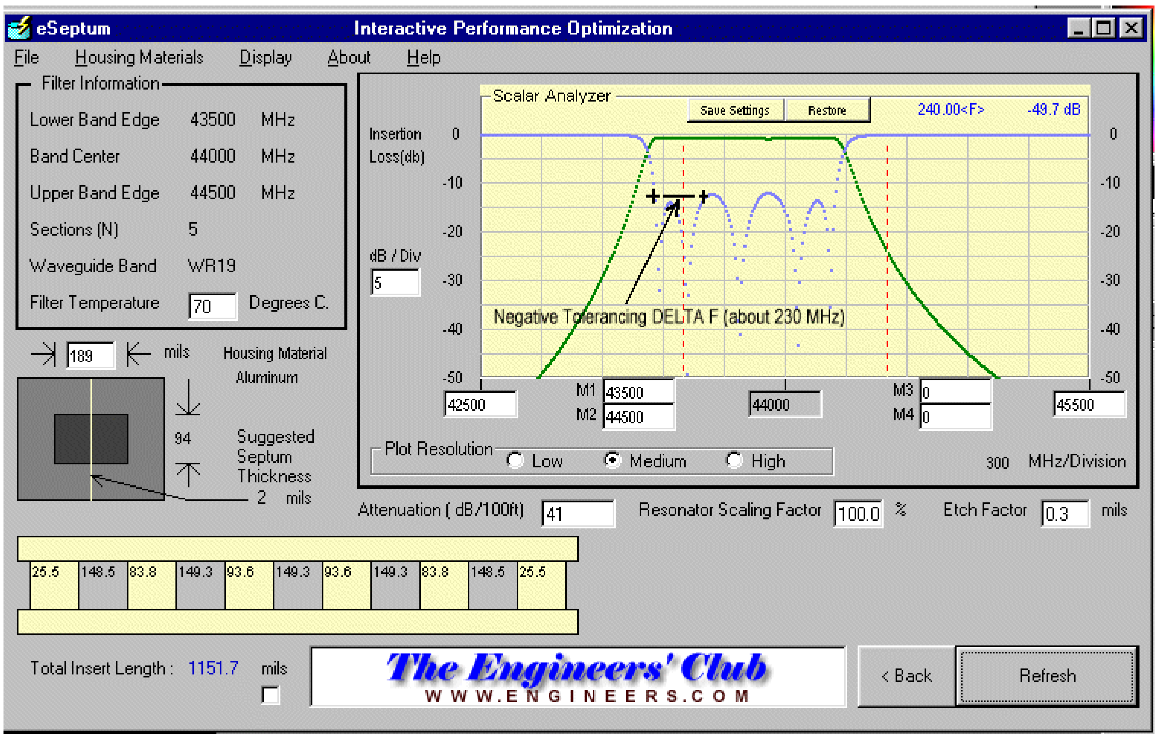
Make a note, for later use, the **FILTER BANDWIDTH NEEDS TO BE WIDENED BY <u>130MHz</u>** to meet the nominal design at room temperature.

Next, check for NEGATIVE FREQUENCY MOVEMENTS due to TEMPERATURE, ETCH FACTOR, and WAVEGUIDE TOLERANCE.

Remember, your MOUSE DELTA F Reading is STILL MARKED FROM THE LEFT MOST EQUAL RIPPLE POINT of your filter.

1. **CHANGE** the WAVEGUIDE "A" dimension box to read 189 mils (+1 mil from nominal 188 mils).
2. **DOUBLE-CLICK** the ETCH FACTOR box to AUTOFIL a "typical" etch tolerance for this thickness of septum material.
3. **CHANGE** the TEMPERATURE box to 70 Degrees Centigrade
4. **PRESS** "REFRESH" for the NEGATIVE TOLERANCE PLOT

SCREEN THREE



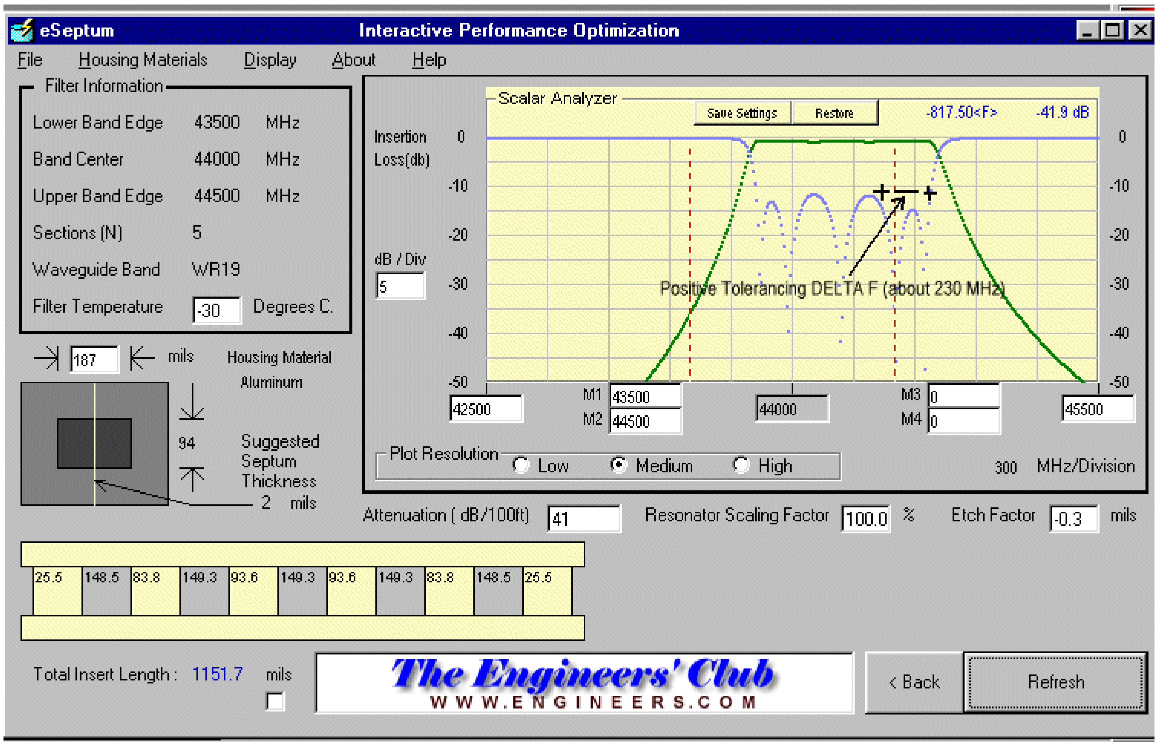
NEGATIVE TOLERANCE FREQUENCY DRIFT

This measurement shows the filter design will drift about 230MHz lower with worst case tolerance. Note this value (230MHz) for future use.

1. **CHANGE** the variables back to the NOMINAL Values: Waveguide "A" dimension = 188 mils, Temperature 25 Degrees, and Etch Factor to 0.00
2. **PRESS** "REFRESH" to get your nominal filter response back on the screen.
3. **LEFT CLICK** the mouse to get into ABSOLUTE FREQUENCY MODE
4. **POSITION** the MOUSEPOINTER CROSSHAIR on the RIGHT MOST EQUAL RIPPLE point of the filter return loss response.
5. **LEFT CLICK** the mouse to return to "DELTA F" mode.

6. **CHANGE** the WAVEGUIDE "A" Dimension to 187mils, the ETCH FACTOR to -0.3 mils, and the TEMPERATURE to -30 Degrees Centigrade.
7. **PRESS** REFRESH and move the MOUSEPOINTER Crosshair to the UPPER FREQUENCY TOLERANCE point (the right most equal ripple point).
8. **READ** DELTA F to find the filter **POSITIVE tolerance drift.**

SCREEN THREE



POSITIVE FILTER DRIFT WITH TOLERANCE AND TEMPERATURE

The POSITIVE tolerance and temperature drift is about 230MHz for this filter.

Lets do some housekeeping:

1. **CHANGE** the ETCH FACTOR back to 0.00, the temperature back to 25, and the Waveguide "A" dimension to 188 (back to nominal values).
2. **ENTER** 42000MHz in the MARKER3 data box
3. **ENTER** 46000MHz in the MARKER4 data box
4. **ENTER** 41000MHz in the START FREQUENCY data box
5. **ENTER** 47000MHz in the STOP FREQUENCY data box
6. **PRESS** REFRESH to get all the markers on the screen.

PRESS STORE SETTING to return to these display settings after modifying the filter design requirements accounting for the needed excess bandwidth to compensate temperature and tolerance issues.

The Filter Needs to be redesigned for extra bandwidth:

- 130MHz Shortfall on initial design
- 230MHz Negative tolerance drift
- 230MHz Positive tolerance drift

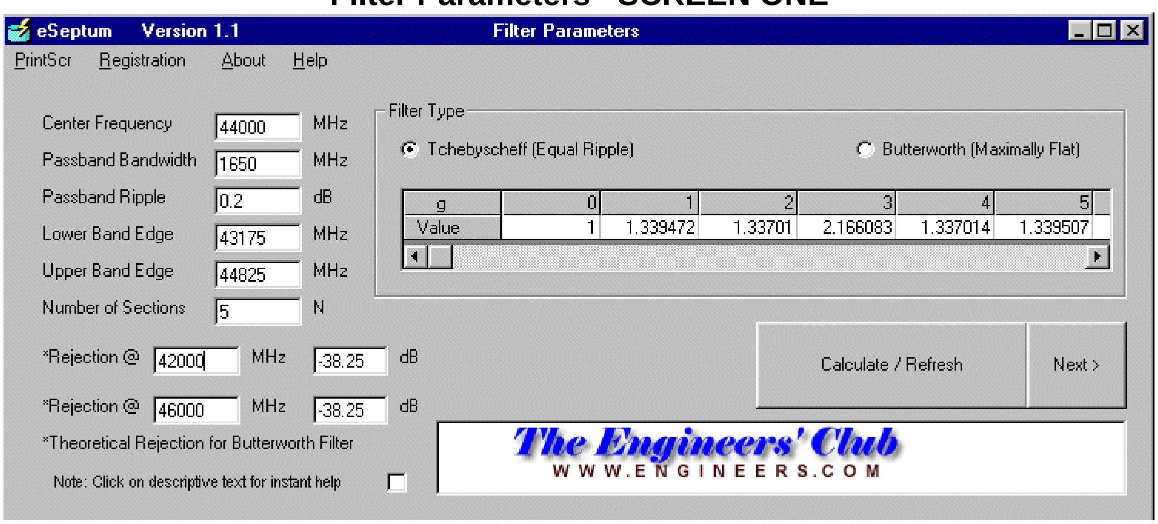
Add all the above tolerance together to find your TOTAL design shortfall.
(130 + 230 + 230 = 590 MHz)
The Total Extra Bandwidth needed = 590 MHz, Round up to 650 MHz.

PRESS <BACK Twice to return to original design screen (or mouse click on the Parameters screen).

CHANGE PASSBAND BANDWIDTH by Adding 650MHz to the original 1000MHz requirement for a new requirement of **1650MHz.**

PRESS REFRESH TO CALCULATE NEW g VALUES

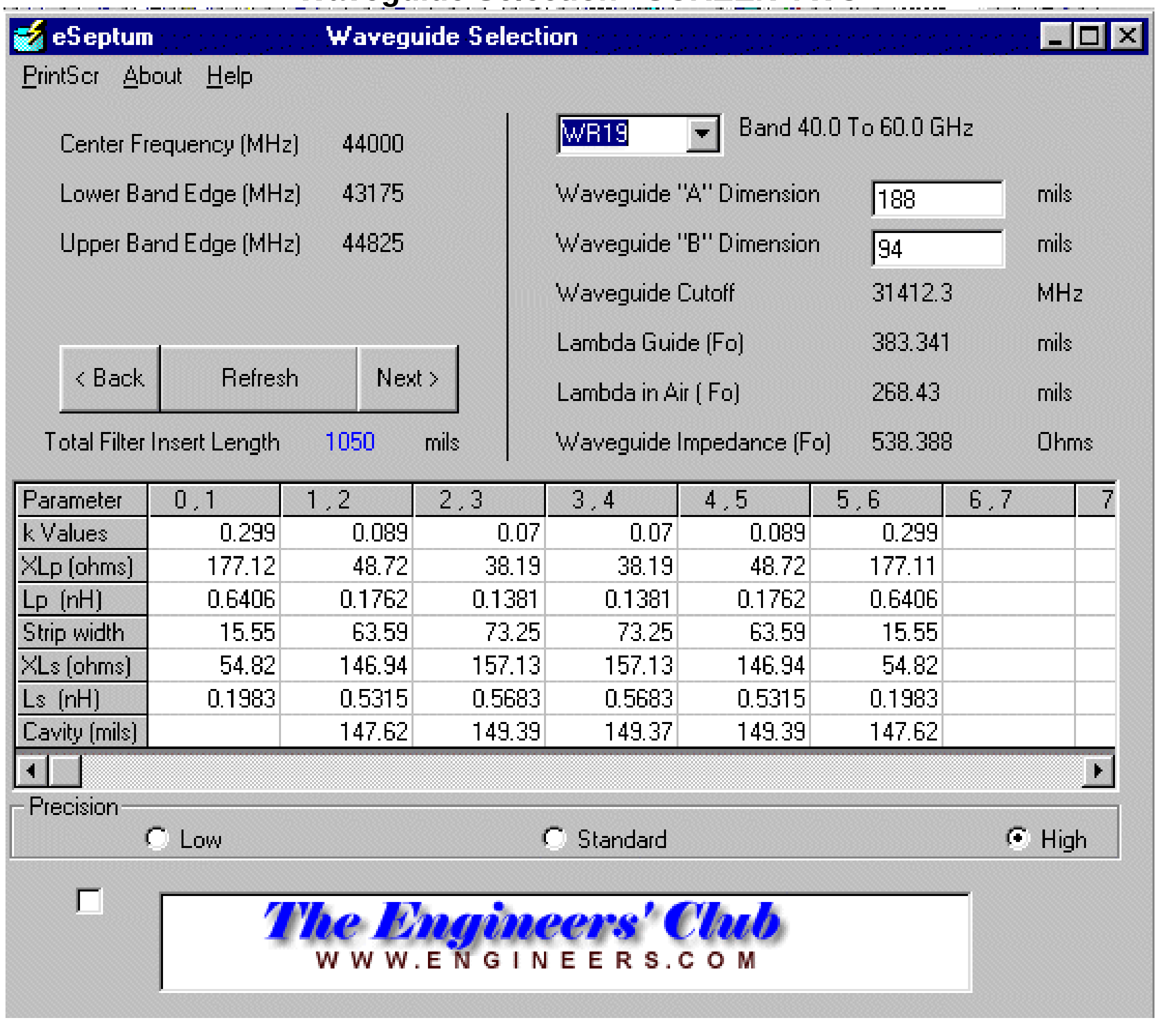
Filter Parameters SCREEN ONE



MODIFIED VALUES, 1650MHz BANDWIDTH, NEW g VALUES CALCULATED

PRESS NEXT> to calculate and move on to the WAVEGUIDE SELECTION SCREEN (Screen Two)

Waveguide Selection   SCREEN TWO



Parameter	0 , 1	1 , 2	2 , 3	3 , 4	4 , 5	5 , 6	6 , 7	7
k Values	0.299	0.089	0.07	0.07	0.089	0.299		
XLp (ohms)	177.12	48.72	38.19	38.19	48.72	177.11		
Lp (nH)	0.6406	0.1762	0.1381	0.1381	0.1762	0.6406		
Strip width	15.55	63.59	73.25	73.25	63.59	15.55		
XLs (ohms)	54.82	146.94	157.13	157.13	146.94	54.82		
Ls (nH)	0.1983	0.5315	0.5683	0.5683	0.5315	0.1983		
Cavity (mils)		147.62	149.39	149.37	149.39	147.62		

RECALCULATED VALUES BASED ON NEW “SCREEN ONE” DATA

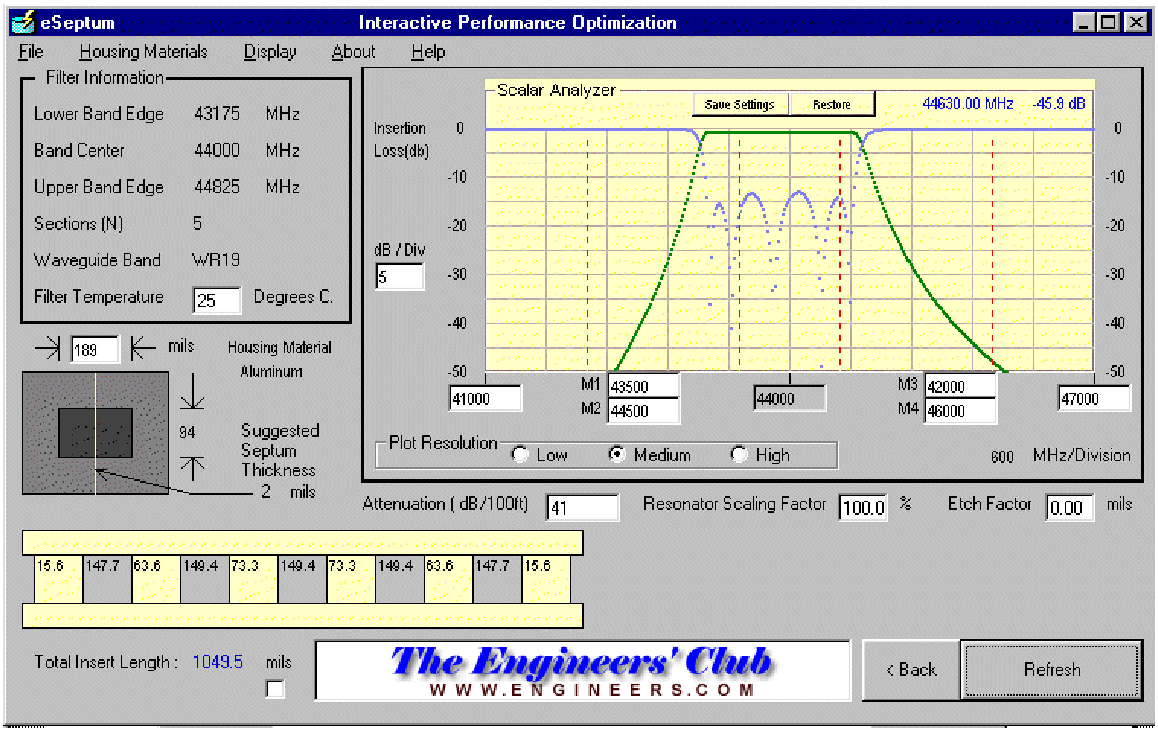
The work was automatically done for you on the WAVEGUIDE SELECTION SCREEN.

PRESS <u>NEXT ></u> to move to SCREEN THREE, Interactive Design Optimization.

PRESS RESTORE to get your "Saved" settings for the display back.

PRESS REFRESH to display your new "wider band" filter.

Interactive Performance Optimization   SCREEN THREE

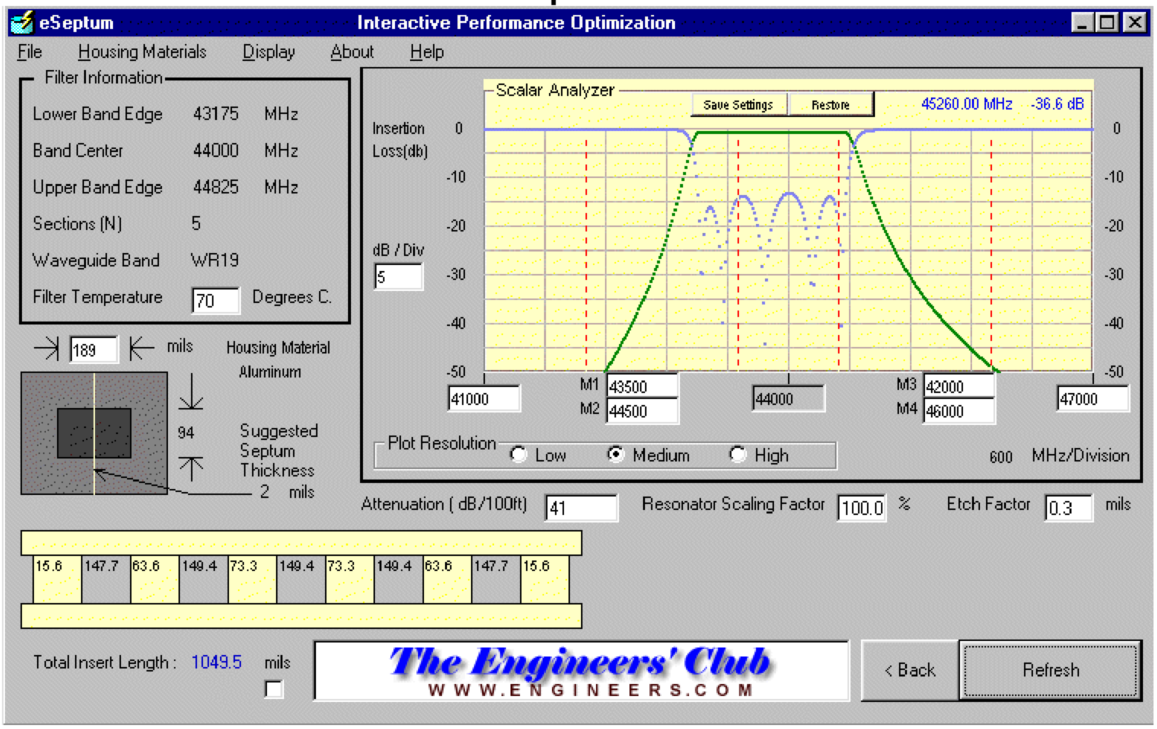


DISPLAY OF OUR "WIDER" DESIGN FILTER

Looks pretty good, and centered up on the desired band, let's check it for temperature and tolerance performance to see how you did.

1. **CHANGE** the TEMPERATURE box to +70 Degrees Centigrade
2. **CHANGE** the ETCH FACTOR box to 0.3 mils (or double-click data box)
3. **CHANGE** the WAVEGUIDE "A" dimension to 189 mils
4. **PRESS** REFRESH to see the NEGATIVE tolerance and temperature drift of our new design.

Interactive Performance Optimization SCREEN THREE

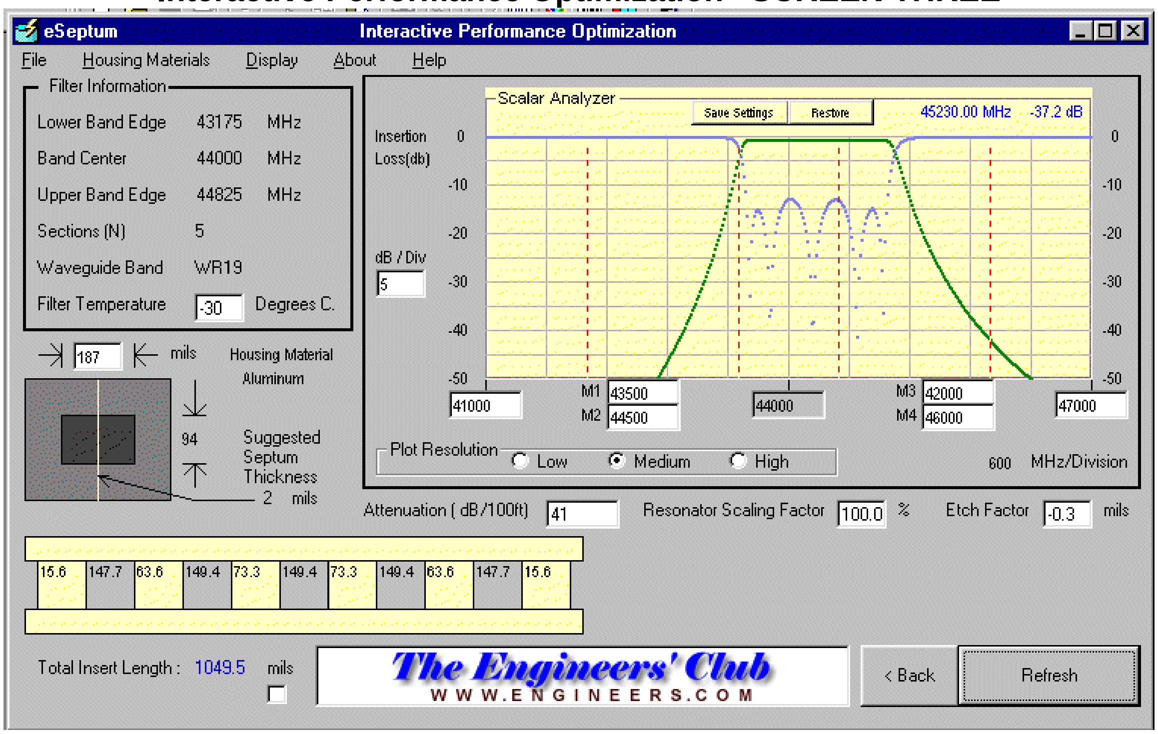


NEGATIVE TOLERANCE AND TEMPERATURE DRIFT PLOT

Let's check the other tolerance extreme now:

1. **CHANGE** <u>TEMPERATURE</u> box to -30 Degrees Centigrade
2. **CHANGE** <u>ETCH FACTOR</u> box to -0.3 mils
3. **CHANGE** <u>WAVEGUIDE "A"</u> Dimension to 187 mils
4. **PRESS** <u>REFRESH</u> to plot positive tolerance and temperature drift.

Interactive Performance Optimization   SCREEN THREE



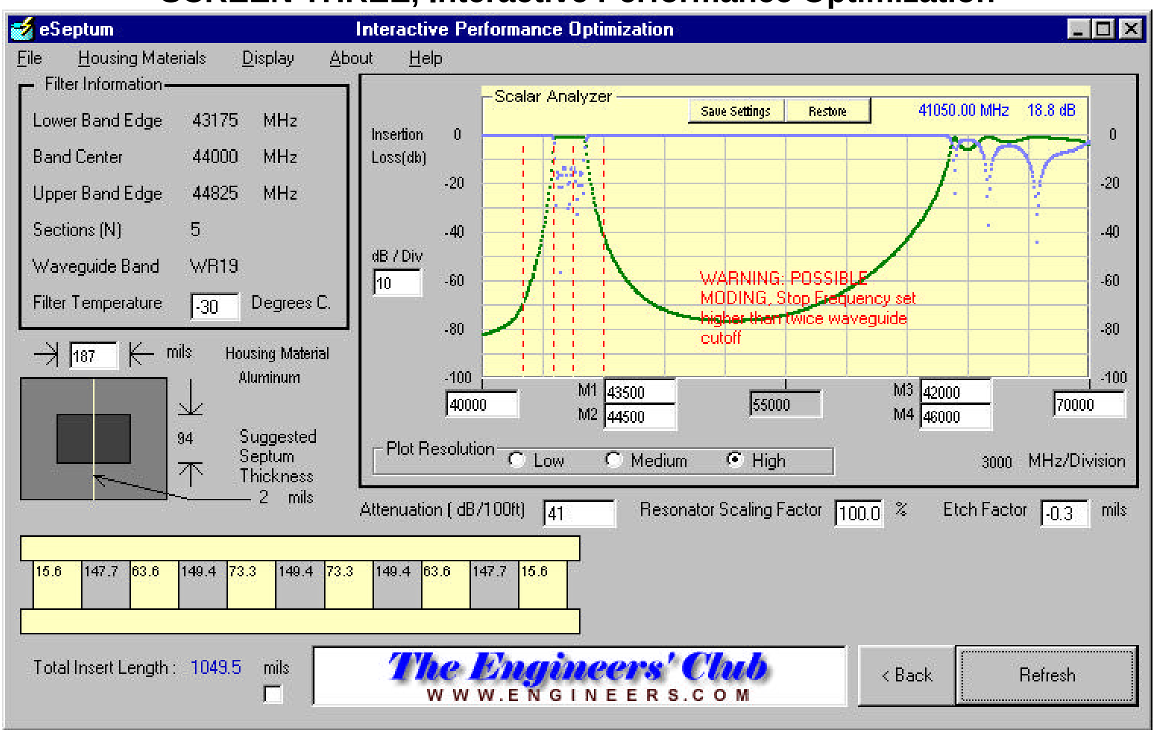
POSITIVE TOLERANCE AND TEMPERATURE DRIFT PLOT

It is seen that the filter now has enough bandwidth but is centered "just a little bit high". This can be easily fixed by lengthening all the resonators by an equal amount on the layout (this will be left as an exercise for the user). Try adding about 2 mils to each resonator length (147.7 to 149.7, 149.4 to 151.4, etc.), that should center the design.

Let's check for second pass band responses up to 70GHz or so:

1. **CHANGE** the START FREQUENCY to 40,000mhz on the Scalar Display
2. **CHANGE** the STOP FREQUENCY to 70,000mhz on the Scalar Display
3. **CHANGE** the "db/Div" box to 10dB/Division on the Scalar Display
4. **CHANGE** the PLOT RESOLUTION to High (we need lots of data points)
5. **PRESS** REFRESH to plot filter response up to 70GHz

SCREEN THREE, Interactive Performance Optimization



SPURIOUS RESPONSES, SECOND PASSBAND PLOT

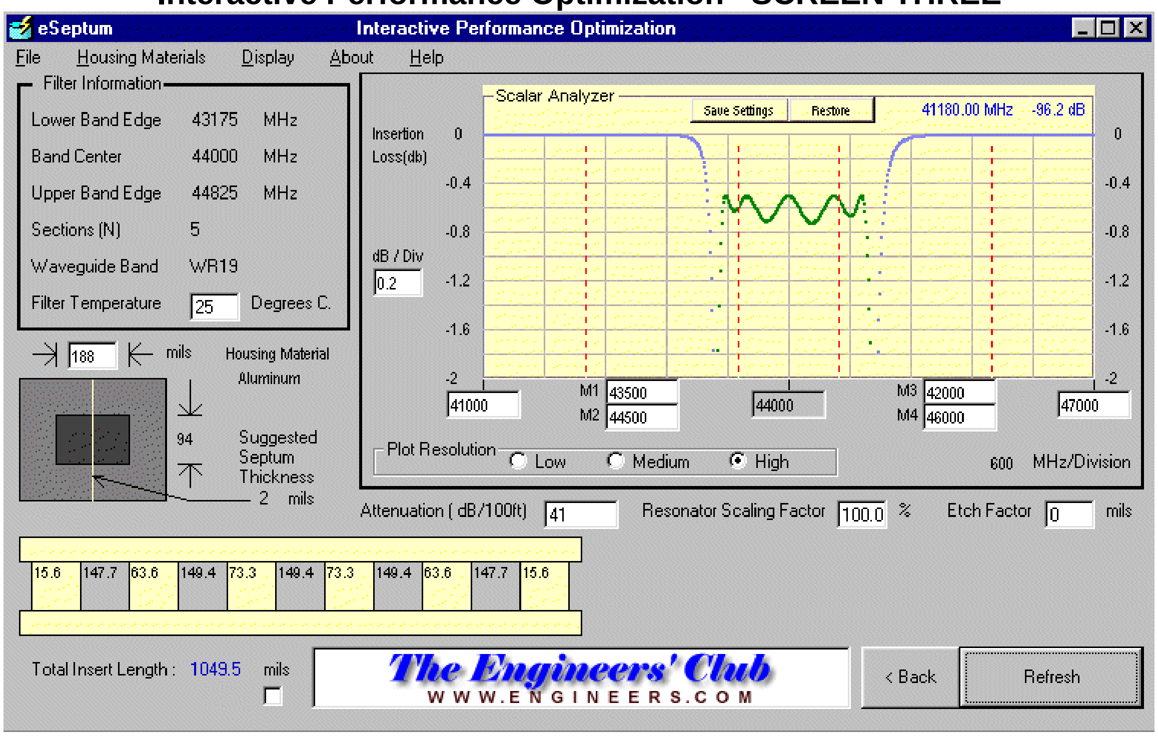
Using the MOUSEPOINTER crosshair, the rejection is measured at about 20dB at 60GHz. This DOESN'T meet our original goal of 20dB loss minimum from 55 to 65 GHz. Also, we have a warning that the waveguide is operating above twice cutoff and possible moding can be present.

For design margin, adding a LOWPASS Filter to the Radio Design would be the safe way to proceed. It could always be removed at a later date if specifications could be met without the Lowpass Filter.

Lastly check Ripple, and then we're ready to give the design to drafting

1. **PRESS** RESTORE to bring the original settings back to the display.
2. **CHANGE** the "dB/Div" box to 0.2dB/Div.
3. **CHANGE** the Temperature, Waveguide "A" dimension and ETCH FACTOR back to nominal values.
4. **PRESS** REFRESH to sweep the ripple response of the filter.

Interactive Performance Optimization SCREEN THREE



PASSBAND RIPPLE PLOT

Your filter has a nominal insertion loss of 0.5dB with a ripple of about 0.2 dB.

CONCLUSIONS:

We have quickly designed and verified for manufacturing tolerances and temperature a 44GHz Bandpass filter.

This filter should be easily manufactured with inexpensive material and should meet all the requirements (save one) in a production environment.

- The design criteria of 44GHz +/- 500 MHz was easily met
- The Rejection criteria of 30dB at 42 and 46 GHz was met with plenty of margin.
- Bandpass Ripple of 0.2dB was met
- You identified a possible second passband response problem that may need to be corrected by adding a lowpass filter.

Some Caveats:

The RESONATOR SCALING FACTOR on Screen Three is used to align the program with "REAL WORLD" measured performance. The septums appear just a little longer than their physical length due to transition effects from waveguide into the septums. A good "Rule of Thumb" value for Resonator Scaling Factor is 102%. This gives results closely correlated with measured data on several different frequency bands.

To Adjust For Scaling Factor:
CHANGE the Resonator Scaling Factor to 102% and SHORTEN all the resonator dimensions by equal values (try, 2 mils each) to bring the filter back to center frequency.

While you will be able to design filters with over 20dB return loss using eSeptum, a practical production value for ease of manufacture would be 15dB. This is primarily due to etch factor variation along the length of the filter insert and slight errors in the algorithms used to predict septum inductance.