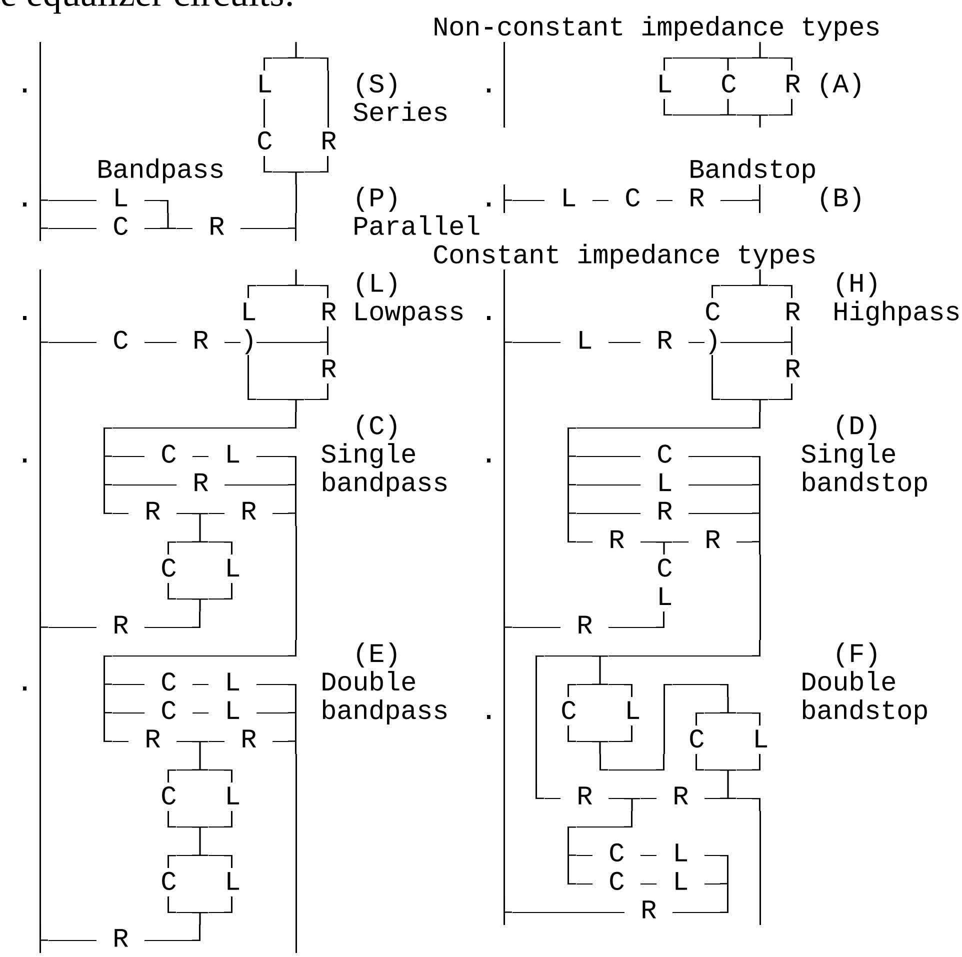
Group delay and amplitude equalizer

The equalizer module is an automatic or manual iteration, graphic display method of design for group delay or amplitude equalization of filters. The main feature is the ability to read in delay or amplitude data from analysis, a disc file or the keyboard and add the theoretical response of one or more equalizer sections making a graphic display of the combined responses. By manually adjusting the specifications of each section after the automatic least-squares optimization is complete, equalization can be optimized to any specifications.

The design Zo is established in the Parameter menu. This will be the impedance of the system into which the equalizers will be working. All sections will have the same Zo.

If the filter to be equalized is saved to disk before beginning the equalizer design, it may be joined to the completed equalizer for analysis.

Amplitude equalizer circuits:



Component losses in passive filters cause the passband to "sag" in the area of the cutoff frequencies. The amplitude equalizer module will design any of the networks that have a loss characteristic that is opposite to the "sagging" of a lowpass or highpass filter. These can be used to compensate for the sag so long as the increased loss can be tolerated.

The constant impedance networks shown are the most complex but provides a constant impedance and will not upset the return loss of the filter it is being used to correct, even with extreme correction.

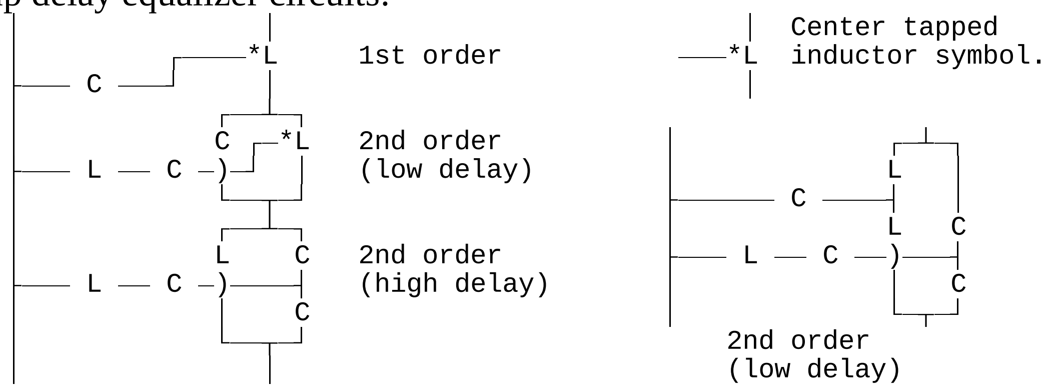
The series and parallel (S and P) non-constant Zo equalizers are much simpler circuits and will fill needs where the correction is not extreme. These two will have a slight effect on return loss.

The networks can be used on filters that display a passband "sag" that is non-symmetrical, such as a lowpass, highpass or even a bandpass that shows a passband "tilt" (such as a wideband tubular circuit).

The design equations for amplitude equalizers are concerned with the total dB of correction, and the slope of the correction over frequency. The needed data is the frequency (Fo) of least loss, and the frequency (F2) where the sag is roughly HALF (1/2) the total. For example, assume you have a lowpass filter that was designed with a "last ripple" cut off to be at 50 Mhz. At the last ripple frequency of 50 Mhz, you measure 1.0 dB insertion loss, you would then look for the frequency at which the loss is .5 dB. This technique works well with single passband equalizers. The dual networks (options E and F) require a slightly different system of specifying their parameters initially because both passbands (or bandstops) must be specified at the same time. For these, specify one equalizer center frequency as with the single band equalizer. The other will be positioned symmetrically on the other side of the frequency range displayed on the plot.

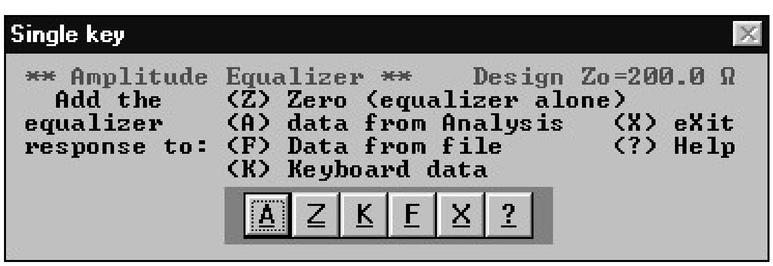
The performance curves for amplitude equalizers are evaluated by actual analysis and will be slower than those for group delay. This allows component Q to be taken into account however. Q factors are those shown in the Assumed Q window on the main control menu.

Group delay equalizer circuits:



The user must select if he needs a 1st or 2nd order delay equalizer manually, but the decision between the low or high delay circuits is automatic. The 1st order circuit shows increasing delay at lower frequencies. The 2nd order equalizer has a delay peak at some specified frequency. All 4 equalizers are constant Zo all-pass networks.

When group delay equalization is being done, the initial display will look like the window shown below. Amplitude equalization will display the appropriate heading. This selects the delay or amplitude response to equalized.



[X]-Quit and exit without doing anything.
[A]-data from Analysis

The last analysis run in memory (and therefore the group delay or amplitude response of some filter to be equalized).

[Z]-Zero (equalizer alone)

This mode allows the equalizer sections to be evaluated alone. The response of each section is normally added to some other number to yield a total response. If the data to be equalized is zero at all frequencies, only the response of the equalizers is displayed.

To graphically display the response of the equalizer, a frequency scale must be set up. You will be asked how many points, and the frequency limits across which to graph the response.

[F]-data from File.

Data to be equalized (up to 100 points) can be read form a disk file having the extension ".eqd". The default name is kbd_data.eqd. Linear interpolation is used to derive data for any frequency that is not directly specified. This means that the frequency points do not have to be uniformly spaced. The recalled data will be displayed on a plot having 100 points no matter how may points are provided in the data. The frequency range is that of the highest and lowest frequency in the data.

The format for the data is simply: frequency , data (delimiter is the comma). All frequency and data must be in the notation selected. Data can be amplitude (dB) or group delay (nSec, etc.). When the file is used by the analysis module the choice of amplitude or group delay is selected when the |- EQ Data -| "element" is inserted into the network (see chapter 16 on the analysis module).

[K]-Keyboard data

In the event you might want to equalize the measured response of a network, or design to a written specification, the measured data may be entered into the program by the Keyboard option. The same routine is used to identify the number of points and frequency limits for the graph as is used with the Zero mode.

Specification data must be entered into the program in an inverted fashion such that the required delay entered plus the calculated response of the all-pass networks will add to zero. To do this, simply enter each point as a negative number. After all the data is keyed in it is saved in a disk file named kbd_data.eqd so that it can be edited by a text editor or word processor and recalled later by the [F] file option. The notation selected at the time is written at the top of the file. It is only a reminder to the user. The notation is NOT read back in when the file is later recalled.

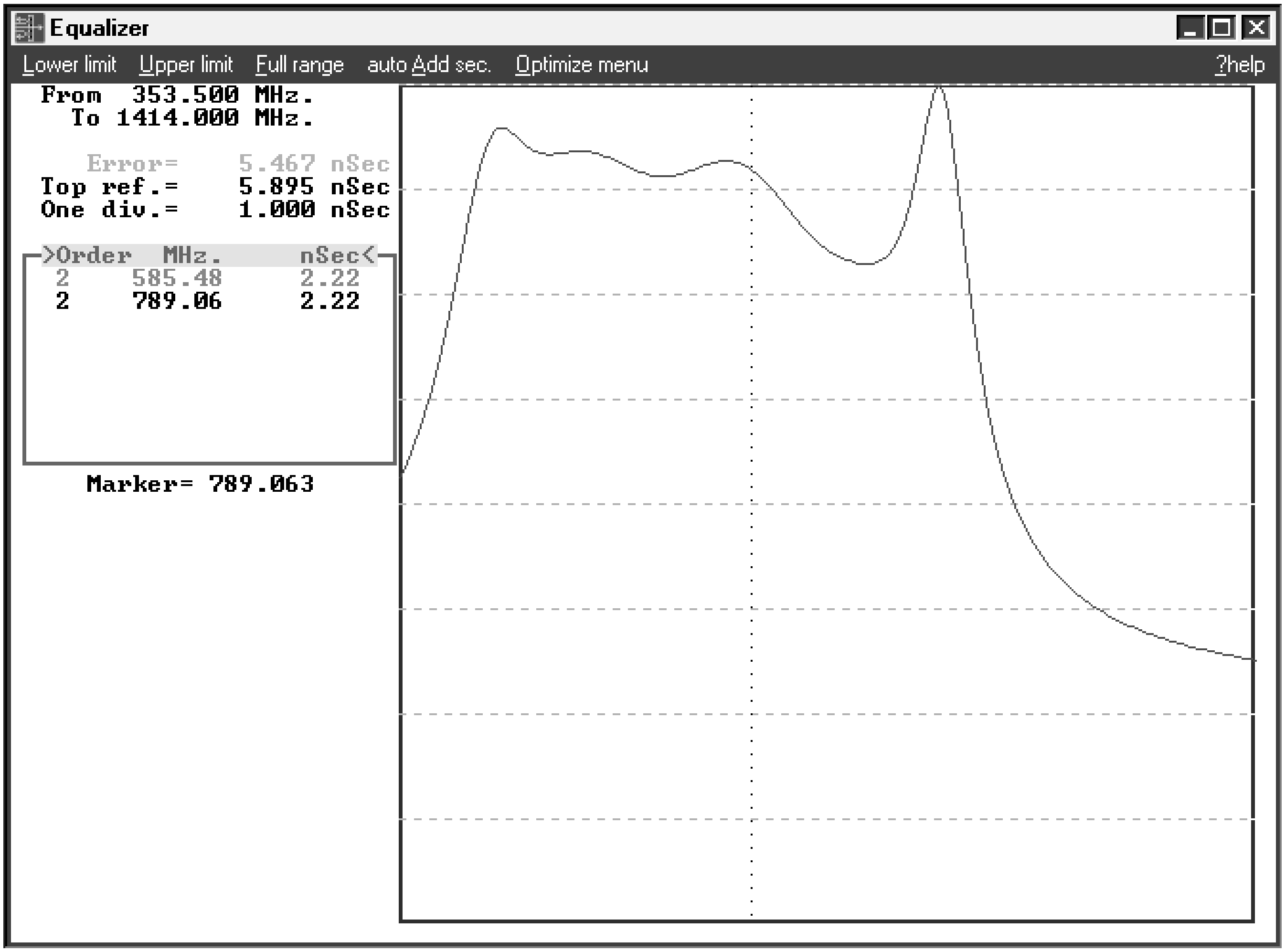
Operation

This module is divided into two separate menus from here on. The two menus will be referred to as the "Marker" menu, and the "optimization" menu. Along with either menu, there will be a graphic display of data taken from the keyboard, or from analysis.

To the left of the graphic display will be digital data to explain the vertical scale of the display, and an area showing the specifications of each of 8 possible sections that can be designed.

All scale factors are automatic and in a 1-2-5 sequence.

The Marker menu will appear first:



The marker menu provides these options:

Lower limit

Causes the position of the marker to become the new lower frequency limit of the graphic display. The display is redrawn.

Upper limit

Used to set the upper frequency limit of the graphic display. The display is redrawn.

Full range

Causes all available data to be displayed. Use this to widen the bandwidth of the graphic display.

Auto Add sec..

The auto add section. option is a quick and easy way to insert an additional equalizer section (except 1st order delay sections).

Optimize menu

Moves from the Marker menu to the optimization menu. All changes made using the marker will be locked in.

?-help

Displays a series of help screens.

When the marker menu is displayed, so is the marker itself. It is a vertical dotted line. It will initially appear in the middle of the plot. It may be moved left or right with the keyboard arrow keys or it can be grabbed and dragged using the mouse left button. The frequency of the marker is displayed to the left of the display.

When equalizing delay:

A second order "peak" will be automatically positioned at the frequency of the marker by selecting the auto Add sec menu option. This feature can NOT be used with a first order network.

The delay value automatically picked for the new section will be the average of all the existing sections, or equal to the delay at the marker if the feature is used to start the first section.

It should be noted that the delay peak of a second order all-pass network having a very low value of delay will be lower in frequency than that specified. This could cause some confusion.

When equalizing amplitude:

The frequency of the marker will be the frequency of least attenuation (Fo) of the added section. The frequency F2 and the associated dB spec will be determined by the attenuation at the cursor and difference in frequency from the edge of the display to the marker. A good starting point is to move the cursor roughly to the point of half the "sag". When specifying the dual equalizer networks position the marker at the middle of the frequency range to be equalized.

Optimization menu

The only difference in appearance between the marker menu and the optimization menu is the change in menu items at the top of the window. The marker menu also has the marker itself which is gone when optimizing.

The optimization menu options:

These commands are common to both group delay and amplitude equalization:

eXit

When the results are satisfactory, you can exit from the equalizer module and save the design. The design can be analyzed alone, or joined to any other network with the Join option on the main control menu.

Manual Add sec.

Use this to add an additional section by keying in the specifications for the section to be added. This is the only way to add a 1^{st} order delay equalizer.

Remove sec.

This command will delete the a section. A dialog box will come up to ask which section is to be removed.

Tune on/off

The tune mode brings up a group of buttons on the left of the window that are used to refine the equalization done by the automatic mode. This will toggle the tune mode on and off. Selecting the “auto Opt” mode will turn the tune mode off.

Back up

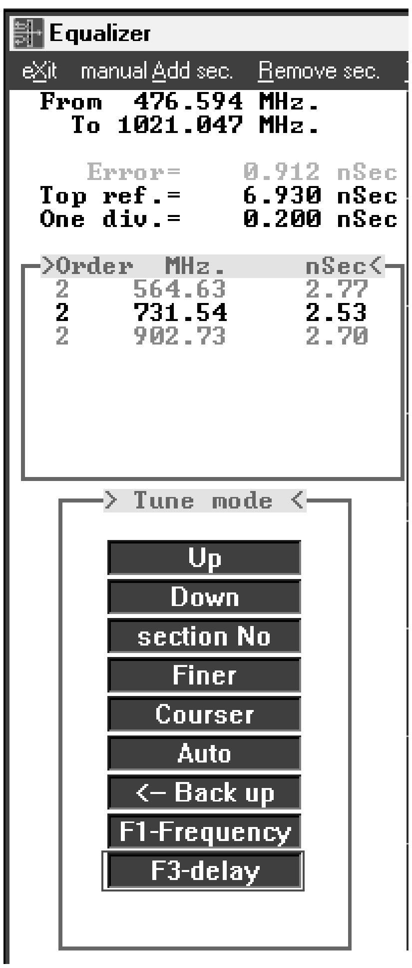
Back up will Un-do the last auto optimization.

auto Opt

This selection will perform a "least squares" optimization of one pass over all sections and all parameters. You will want to use this several times before moving on to touch up the design manually.

Marker menu

Used to return to the marker menu to widen the displayed frequency or add another equalizer section.



The TUNE mode

The tune mode comes on when selected from the optimization menu and is used to manually change the specifications of each section, one at a time to refine the equalization done by the fully automatic optimization. A set of buttons is used to control the optimization.

[Up] [Down]

Adjusts the selected parameter either up or down by an amount that can be adjusted by the [Fine] and [Coarser] buttons.

[section No]

The section that is being adjusted is highlighted in the specification area above the buttons. This button will change the active section by moving the highlight through the list from top to bottom.

[Finer] [Coarser]

These two buttons adjust the steps made by the [Up] and [Down] buttons.

[Auto]

Each selected parameter my be submitted to automatic optimization by the least squares error method by pressing this button.

[<–Back up]

This will back up from the last [Auto] operation.

The buttons at the bottom of the group select which parameter is being optimized. The selected button (parameter) is boxed in to identify it.

[F1-Frequency] [F3-delay]

These two buttons appear when designing group delay equalizers.

[F1-Freq 1] [dB] [F2-Freq 2]

These three buttons appear when designing amplitude equalizers.

A practical example

To illustrate how a typical filter can be equalized for group delay, a filter used as an example of the use of the "D" coupling will be equalized. This filter is described on page 7-5. Begin by duplicating this design. Since no load / source impedance matching was used on that example, you will also need to reset the matcher and choose shunt C matching on one end of the filter and shunt L matching on the other (options F and G, respectively). This configuration will preserve the equal delay peaks of the filter and allow the equalizer to be series joined directly to it later.

1 - Begin by duplicating the design example on page 7-5 with impedance matching added.

2 - In order to get a group delay curve to equalize, analyze the filter form 95 to 105 MHz. This frequency range includes both group delay peaks.

3 - SAVE THE BANDPASS DESIGN TO DISK! If you design the equalizer without saving the filter first, it will be lost!

4 - Choose from the menus: Design | Equalizer | Group delay.

5 - When the parameters menu appears, you must set the design Zo to match the Source impedance that the filter was matched to. It will be set at the natural design impedance of the filter you last designed (10 Ohms in this case). You will have to change it to 50 Ohms.

6 - Press the [CALCULATE] button.

7 - Select [A] from analysis button on the starting dialog box to bring in the analysis data having the group delay performance of the filter to be equalized.

8 - You should now see the group delay curve of the filter by itself. Move the vertical dotted line marker to the lower group delay peak (at 95.4 MHz.) by using the keyboard left and right arrow keys or by dragging it with your mouse by pressing and holding the LEFT button down. Press the L keyboard key to set the lower frequency limit over which optimization is to be done. Similarly, set the upper limit by moving the marker to the upper frequency delay peak (104.8 MHz.) and pressing the R key.

9 - To insert the equalizer sections, move the marker to the middle of the passband, that is, the point of least delay (100.1 MHz) and press the A (auto Add.) key. This defines the initial position and delay of the first equalizer section. Obviously, one section is not going to be enough. To add another section, move the marker to the upper minimum delay point (103.1 MHz.) and press the A key again. Also, add a third equalizer at the lower delay dip at 97.1 MHz.

10 - Select the Optimize menu option to bring up the optimization menu.

11 - Select **auto opt** by pressing the A key. Do this again after the optimization stops. You can now pick sections and parameters as you like adjusting them to improve the total error by entering the Tune mode.

12 - When you are done, select eXit from the menu and join the equalizer to the filter by selecting Join feature from the main control menu. The combination of equalizer and filter may be analyzed to confirm the results.