Tracker
Version 1.0
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Operating Instructions

Introduction
The program performs two main functions. First, it calculates and optimizes the padder and trimmer values for the local oscillator tank circuit in a superheterodyne radio. Second, it determines padder and trimmer values for bandspreading a tuning capacitor which is useful in any type of radio.

This program differs from other tracking calculators in that it does not ask the user to pick tracking frequencies. Doing so, even using reasonable looking tracking frequencies, can provide surprisingly sub-optimum results, especially when dealing with large frequency bands such as the MW broadcast band. This program determines optimum trimmer and padder values using its own internal optimization algorithm. Specifically, it uses Nelder & Mead's Downhill Simplex method, with a choice of several custom designed error functions.

In the following description, the terms "Series" and "Padder" capacitor mean the same thing. Likewise, "Parallel" and "Trimmer" mean the same thing. All frequencies are in kHz. All capacitances are in pF. All inductances are in μH.

The model used for the RF and LO tank circuits is as shown in Fig. 1. Stray capacitance refers to all circuit capacitances which are not accounted for by the physical capacitors, and which affect the tank circuit. It includes self-capacitance of the coil, wiring and other circuit components.

Fig. 1, Tank Circuit Model for both RF and LO
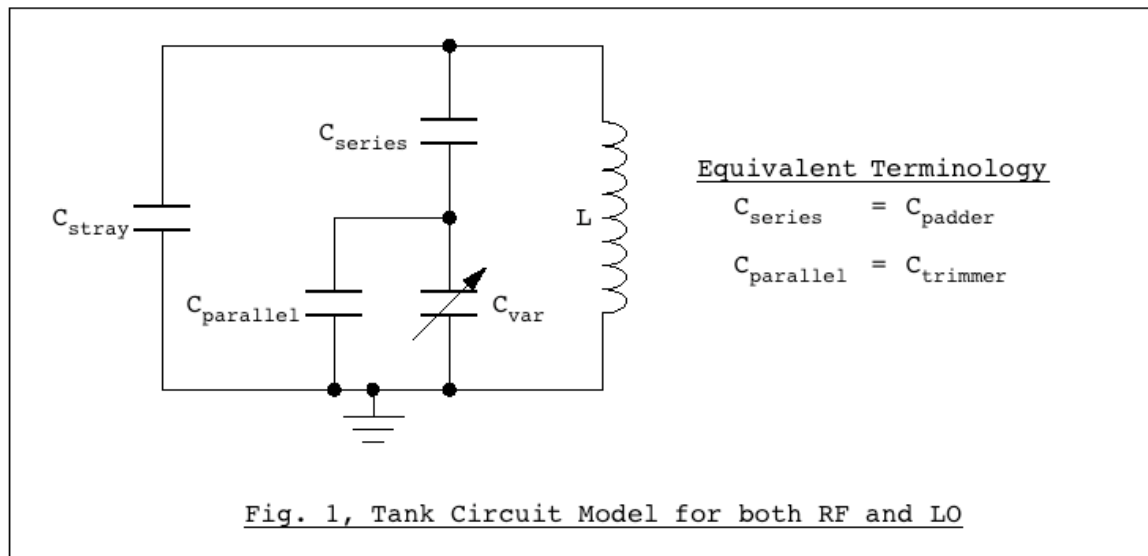
Starting Up
When you run the program, you will see the Tracking Calculator window. To perform tracking calculations, use this window. For bandspreading and capacitor characterization, skip to the Bandspreading/Characterization section of this documentation.

Tracking Calculations
The tracking calculator window presents you with some data entry fields which are hopefully self-explanatory:

Lower Freq: Low end of the desired band in kHz;

Upper Freq: High end of the desired band in kHz;

IF: The desired Intermediate Frequence in kHz;

Exact Freq's 1, 2, 3: Leave blank unless you want the program to use this classic (but sub-optimum) method to determine the trimmer and padder to fit these frequencies;

RF Capacitor: Enter the value in pF (with plates fully meshed) of the RF section of the tuning capacitor;

L.O. Capacitor: Enter the value in pF (with plates fully meshed) of the LO section of the tuning capacitor;
The assumption is made that the minimum capacitance value is low enough to hit the high end of the band. (See below about bandspreading.)

RF Series: If you are bandspreading the tuning capacitor with a padder, then enter its value in pF here;

RF Parallel: If you are bandspreading the tuning capacitor with a trimmer, then enter its value in pF here;

RF Stray: This accounts for stray capacitance in the RF tank. You can generally assume a value between 10 and 20pF;

L.O. Series: Leave blank unless you want to a manual tracking calculation. This will be calculated automatically;

L.O. Parallel: Leave blank unless you want to a manual tracking calculation. This will be calculated automatically;

L.O. Stray: This accounts for stray capacitance in the LO tank. Again, you can generally assume a value between 10 and 20pF;

L.O. Coil: Leave blank unless you want to a manual tracking calculation. This will be calculated automatically;

"Optimize method" popup menu:
Weighted Peak Error: The recommended method which minimizes the peak errors, with weighting towards the low end of the band.

Peak Error: An equally weighted version of the above.

Mean Error: This method minimizes the mean error, but has the disadvantage that the worst error occurs at the bottom of the band where it is the biggest problem.

Weighted mean error: A weighted version of the mean error method, which gives slightly improved tracking at the bottom of the band, but not as good as the peak error methods.

3 Frequencies: A non-optimizing calculation which determines the trimmer and padder based only on the 3 tracking frequencies entered in the Exact Freq's fields above. If those fields are blank, they will be filled with suggested values, and the calculation will be performed with them. If the stray capacitance is zero or blank, then the calculation is an exact analytical formula (a cubic equation) from F. Terman, 'Radio Engineering.' It does not take into account the value of C_{stray}. If the stray capacitance field contains a non-zero value, then the iterative algorithm is used.

Optimize Button: Click this to have the program find the optimum padder and trimmer values. While this is in progress, the graph in the bottom of the window shows the tracking error curve as it converges on the final answer. The tracking error will be an S-shaped cubic curve. The values of the required trimmers, padders and inductors are also displayed.

Looking at the Results
Although the peak error methods give the best results, the peak error function is not a smooth curve (the first derivitive is discontinuous). It's possible for the optimization routine to get stuck on a flat spot, and hence, not return the optimum value. It will usually be close though. To check convergence, just click the optimize button again. The routine will use the previously calculated values as starting values, and should converge quickly. For peak error, when optimized, the four error peaks (the left end of the error line, the bottom hump, the top hump, and the right end of the error line) should be exactly the same distance from the x-axis. For weighted peak error the distance of the four peaks from the x-axis will increase linearly from left to right. From this, it's quite easy to see if the values did not fully optimize. This problem does not occur with the mean error methods, because these error functions are smooth.

You may copy the tracking error graph by clicking on it and then selecting "Copy" from the Edit menu or typing ctrl-C (cmd-C on Mac).

One warning: When you click the Optimize button, it uses the current values in the *LO parallel* and *LO series* fields as the starting values for the calculation. If the values are too far off, then the program may be unable to optimize and the error curve will be obviously wrong when it finishes. This can happen if you have done an optimization for one frequency band, and then changed to a new band (or made a change to the IF frequency, etc.). The last calculated values will be way off, and you will have problems. To prevent this, the program will normally clear the *LO series* and *LO parallel* fields when you make a change to another parameter which will significantly affect them. However, in some cases you may need to manually clear these values yourself if continually fails to converge properly. With *LO series* and *LO parallel* fields blank, the program will calculate approximately correct starting values and will have no problem with convergence.

Weighting the error calculation
As mentioned above, the preferred optimization is the weighted peak error method. This deserves a bit of explanation. It is reasonable to assume the local oscillator and RF tank circuits have a Q which does not increase with frequency. I.E., it remains constant or decreases as frequency goes up. Consequently, the bandwidth of the tank circuit increases as frequency goes up, and decreases as frequency goes down. For this reason it is important to have the tracking as close as possible at the low frequencies where bandwidth is narrow. At the higher frequencies. errors in tracking are more forgivable since the bandwidth of the RF stage is higher. In order to perform a weighted calculation, as the unweighted error is calculated at a each frequency, it is divided by that frequency. This results in best tracking at the bottom of the band.

It should be noted at this point, the tuning of a superheterodyne receiver is determined by the local oscillator, and the IF center frequency and IF passband. The effect of the RF circuit is simply to reject image frequencies. Hence, it need not and generally does not have a high Q as does the IF stage of the radio.

Other functions of the Tracking Calculator
Calculate Button: Click this if you have manually entered values in all the RF fields and LO fields, to draw the tracking error curve for those values. Use this if you have an existing set of components, and you want to see how well they will track.

Animate Button: This shows an animation of what happens when the trimmer and padder are varied but constrained to have perfect tracking at the lower and upper end of the band. It's not particularly useful, but is fun to watch (the first time). Hit the ESC key when you've seen enough.
[Note, at present, unless you have slow computer, the animation is too fast to be useful. This will be addressed in a future version.]

The text box in the upper right of the window, is a diagnostic printout of some intermediate and final variables. It may be removed in future versions.

Bandspreading/Characterization

If you go to the windows menu, and select "Characterize," it brings up another window that lets you see the effect of adding padder and trimmer values to the RF section of the capacitor. This is useful for bandspreading. For example, if you want to build a shortwave receiver to cover the 49 meter band, say 5500 kHz to 7000 kHz, you only need a capacitance ratio of 1.6:1 (which is the square root of the frequency ratio), but a tuning capacitor typically has an adjustment range of 10:1 or more. This window allows you to see the effect of picking different values of RF trimmer and padder, and also shows what kind of linearity you will get on the dial scale. To that end, you need to select the characteristic of the variable cap you are using. Modern ones are midline, but you may also encounter some straight-line capacitance ones. If you have some really old ones they may be straight-line wavelength, or straight-line frequency. (You can also enter the datapoints for a custom capacitance characteristic, then click the C-Fit button to calculate and display the characteristic for the data you have entered). Click the radio button for the capacitor type that you want to use. The characteristic is graphed on the right. Clicking on the graph will cycle though graphs of:
Capacitance vs. Shaft Rotation
Frequency vs. Shaft Rotation
Wavelength Shaft Rotation

The bandspreading calculation data fields are self-explanatory. You must enter the desired frequency range, the actual range of your variable capacitor, and a value for stray capacitance, and then one of the following: C-Parallel, C-Series, Inductance; the other two values will be calculated automatically. Click the radio button beside the value you want fixed, and then click the "Calculate Values" button. This will determine the required values of the remaining two components to give the desired bandspread. Note that as you enter values in the Capacitor Range, Freq Range and C-Stray fields, the limiting values of C-parallel, C-series, and inductance are immediately updated and displayed in blue text to the right of the fields.

Now, click the dial scale button. This will show you what the tuning linearity will look like with the chosen trimmer and padder values for the selected capacitor characteristic. The top half of the scale is with the calculated trimmer, padder and inductor. The bottom half of the scale shows what you would get with the bare capacitor (no trimmer and no padder). You can copy this image by clicking on it and then selecting "Copy" from the Edit menu or typing ctrl-C (cmd-C on Mac).

You can transfer the trimmer and padder values calculated here to the tracking calculator RF trimmer and padder fields, to determine the LO trimmer and padder values for the chosen bandspread. To do this, simply click the *Send to Tracker* button.