Manual for the MathCAD Efficiency Bandwidth Calculators

Currently there are 3 different efficiency bandwidth calculators available as Mathcad documents. The Mathcad version used to create these files is Mathcad 15. Note that older versions may not run the programs.

The simplest program is that of a Class-B amplifier. Although its use is limited the file serves to get familiar with the structure of all 3 calculators in an easy way. If you open the file “Class B Efficiency Bandwidth Calculator”, you will see that the file is spilt into 3 parts: one for input parameters, a 2nd one below the text line “Don’t modify the part below this line”, and a third part called “RESULTS”.

Class-B amplifier

In the “Input parameters” part you can specify the following parameters:

- Center frequency in Hz.
- Signal Bandwidth in Hz. Note that the spacing between the individual tones is set to 10^6 Hz. With defining the signal bandwidth, also the number of tones is defined. Since the center frequency will not be used for an individual tone, the number of tones is the signal bandwidth divided by 10^6. Obviously the signal bandwidth needs to be defined as an even integer times 10^6 to ensure that left and right sidebands have each half of the signal bandwidth.
- Supply voltage, maximum current, transistor knee voltage are all self explanatory.
- The PA load resistance has a default value, but you can also set the value by hand. Note that the resistance value is real, not complex, because this resistance is used to calculate the output power. Any possible imaginary part of the load has to be included in the ABCD matrix (see below).
- The ABCD matrix. This is the ABCD matrix of the entire circuitry between the real load resistance and the intrinsic transistor collector or drain current source. All transistor and package parasitics, like e.g. transistor output capacitance and bondwire inductances, are included in the ABCD matrix. The ABCD matrix has to be written as a function of frequency ω. All parameters that you need to describe the matrix have to be defined before the matrix definition and assigned a value. In the example file you will see the matrix of a simple parallel LC circuit that resonates at the center frequency (see Fig 3). Note that the ABCD matrix must have imaginary components only. The power dissipation by the real elements in the ABCD matrix cannot be calculated correctly by the Mathcad program.

The 2nd section under the text line “Don’t modify the part below this line” should not be changed but provides some intermediate results to monitor the progress of the calculation:

- The plot of A_k vs. k shows a graph of the signal amplitude over time during one full period. The maximum amplitude is normalized to 1.
- The plot of i_k vs. v_k shows the dynamic load-line of the intrinsic transistor drain or collector. This load-line is used to calculate the transistor dissipation.
- The value min(v) gives the lowest drain or collector voltage value. If this value is below zero the calculation proceeds by clipping the voltage at zero volts. Note that clipping the voltage implies that

the transistor dynamic load-line is no longer consistent with the output signal at the load. Therefore the efficiency values that are calculated become less reliable when clipping is needed.

- Also the drain or collector current i_k is clipped to v_k/R_{on} when the voltage falls below the knee voltage. Also in that case the calculated efficiency value becomes less reliable.
- The value max(v) shows the maximum voltage level. Be sure that this value is less than the transistor breakdown voltage.
- The value max(i) gives the maximum current. This should not exceed the value for I_{max} specified at the section “Input parameters”.

The “RESULTS” part returns several values. Except for V_{avg} they all depend on the randomly chosen phases of the individual tones. Every run will return therefore another set of values:

- V_{avg}: this is the average voltage, which must be equal to the supply voltage specified. This is a check that the calculation went well.
- I_{avg}: is the average DC current.
- P_{dc}: is the absorbed DC power
- P_{diss}: is the power dissipated by the transistor
- P_{RF}: is the RF power delivered to the load
- PAR: is the peak-to-average power of the signal
- Efficiency: is the drain or collector efficiency of the amplifier

Doherty amplifier

The file called “Doherty Efficiency Bandwidth Calculator” is hardly more complex that the Class-B calculator. In a Doherty amplifier there are 2 transistors. However, you only need to specify the main transistor and the power back-off point where you want to put the highest efficiency point (parameter γ). The program automatically scales the maximum current and on-resistance for the peak transistor to the right size, and assumes the same supply voltage for main and peak device.

However, you must define 2 ABCD matrices: one of the complete circuitry, including parasitics, between the load resistor and the main transistor intrinsic drain or collector and one for a similar complete circuit between load and peak transistor. By default the main ABCD matrix is that of a quarter-λ transmission line, while the peak ABCD matrix is the identity matrix. Note that the default matrices do not contain any matching or parasitic elements.

In the section that should not be modified some more results are returned than in the Class-B case. Both on-resistances of the main and peak transistors are given as R_{on} and $R2_{on}$ respectively. Also all output parameters as mentioned in the Class-B case are now given per transistor in the sub-sections “Results main transistor” and “Results peak transistor”.

Finally in the 3rd part “RESULTS” the output parameters for the complete Doherty PA are given.

Outphasing amplifier

The file “Outphasing Efficiency Bandwidth Calculator” resembles the calculator of the Doherty amplifier in that it has 2 transistors, but in this case they are of equal size. The parameter γ can be set and has the same meaning as in the Doherty case. Also 2 ABCD matrices, M1 and M2, have to be defined, one for each branch. By default these matrices are both quarter-λ transmission lines. The matrices should not contain the Chireix elements, since the calculator determines the values automatically, based upon the value of γ, and inserts them in the circuit. Conventionally the two matrices are identical. In case you want to try different matrices be aware that branch 1 has outphasing angle $+\theta$, and branch 2 angle $-\theta$. The sign of the outphasing angle determines which Chireix element is placed in which branch.

The “Don’t modify …” part has a few points of attention:

- The signal bandwidth expansion per branch is by default set to a factor of 10 for the BW_{expans} parameter. A Fourier transform is used to translate the time varying outphasing angles into the frequency domain within this expanded bandwidth. This means that the outphasing angles are described having frequency components with 10 times as many frequencies than there are tones in the signal. If you specify a signal bandwidth in the “Input parameter” section that is more than 1/10 of the center frequency, these frequency components will overlap with the center frequency and the calculator will crash. In that case you may reduce the bandwidth expansion factor, but this will lead to an increase of the amplitude modulation of the drain or collector voltage, which will render the efficiency results unreliable.
- The values for min(v) and min(v2), for branches 1 and 2 respectively, may be considerably below zero, especially at wider signal bandwidths. Clipping is applied to zero volt, which reduces the effect of such negative voltages on the efficiency. However, as a general rule, if the negative minimum voltage before clipping is more than -10% of the maximum voltage, the efficiency result may become unreliable, even when clipping is done.
- The “Don’t modify …” part also displays the dynamic load-lines on the intrinsic drain or collector terminals of both transistors. These show more excursions in the voltage-current plane than in case of Doherty amplifiers. This is illustrative of the signal bandwidth expansion per amplifier branch, which is intrinsic to the outphasing architecture.
- Like in the Doherty file, this section also returns the results for each transistor. Despite the seemingly large symmetry between the branches, both transistors may work with rather different efficiencies and output powers, especially when the signal bandwidth is high.

The section “RESULTS” returns the performance parameters of the complete outphasing amplifier, in the same way as in the Doherty file.