Si4012 CALCULATOR SPREADSHEET USAGE

1. Introduction

This application note describes how to use the Si4012 calculator spreadsheet to determine the input parameters of the Si4012 commands, which are needed to achieve the required RF behavior of the radio chip.

The basic transmit parameters of the Si4012 such as output power, modulation type, data rate, and operating frequency are set by using Host MCU Commands. The parameters of these commands can be determined by using a calculator spreadsheet. The Si4012 development kit includes a calculator spreadsheet that helps developers set the arguments of Host MCU Commands to meet their desired design requirements. The latest version of the calculator spreadsheet is available on the Silicon Labs website: www.silabs.com, under the Support→Document Library→EZRadio category. A summary of the calculator operations are given in Figure 1.

Figure 1. Screenshot of the Calculator Spreadsheet

Note: For more detailed descriptions of the Si4012 settings and API functions, please consult the Si4012 data sheet, "Si4012: Crystal-less. RF Transmitter".

AN564

2. Setting up the PA

This part of the calculator is used for determining the correct parameters for the Set Property | PA_CONFIG Command and obtaining optimal antenna impedance values.

More details can be found in Section "2.7. Usage of the Power Amplifier Setup".

2.1. User Inputs—Antenna Setup

■ **Alpha (bLevel/ °C)**: Parameter for temperature variation compensation. If constant radiated power vs. temperature is desired, this constant may be used to compensate the PA drive strength. It can be calculated by measuring the output power at different temperatures while Alpha is set to 0.
Example: Assume 1 dB change in 50 °C temperature variation. The PA output power is programmable in 0.25 dB steps, so 1 dB change is a 4-step variation in PA level setting (bLevel). Therefore, Alpha should be set to 4/50 = 0.08.This parameter has no effect if set to 0.

■ **Approximate Efficiency (%)**: The approximate antenna efficiency used to estimate radiated power. Setting this parameter does not affect the recommended parameters for the API function calls, but is provided to assist the user with estimating the actual radiated field strength.

■ **Reactance Change (%)**: Due to component spreading and the hand-effect, a small variation is possible in the reactance of the antenna. The small-signal sensitivity of antenna impedance will be examined in the specified range while calculating fBeta. The vPA_Tune() API function uses the fBeta parameter to adjust the PA level register in order to attempt to maintain constant output power in the presence of automatic PA output cap. bank variations as a result of antenna reactance changes. See Section "2.8. Calculating Temperature (fAlpha) and Antenna Reactance (fBeta) Compensation Parameters " for more details.The default value (15%) is adequate for many common antenna designs.

■ **Manual Impedance Entry (Yes/No)**: Selects if the antenna impedance (used while calculating the API parameters for the PA to meet the power target, if possible) is calculated by the spreadsheet or if it is entered by the user.

■ **Antenna Real(Z) (Ohms)**: The antenna resistance at the operating frequency.

■ **Antenna Imag(Z) (Ohms)**: The antenna reactance at the operating frequency.
The two fields above, Antenna Real(z) and Antenna Imag(Z), are only used if Manual Impedance Entry is selected and the fields are the equivalent PARALLEL values of the antenna resistance and reactance (that is, not modeled as series R+jX).

2.2. User Inputs—Power Amplifier Setup

The radiated output power of a Si4012-based transmitter depends on many parameters including the antenna characteristics, the output impedance of the PA, the output capacitance bank setting, and the bias current of the PA. The calculator spreadsheet can calculate the required antenna impedance needed to achieve the desired radiated output power or it can estimate the output power given a manually specified antenna impedance. The Power Amplifier Setup has the following input parameters:

■ **Total PA Power (dBm)**: This value represents the Total power as the combined value of the power delivered to the antenna plus the power dissipated internally in the output impedance of the PA. The Total PA Power target can be estimated based on the expected efficiency of the antenna and the desired radiated power target. It represents the total amount of power dissipated in the PA and the antenna. The spreadsheet will always try to hit this target. The result is shown in the Calculated Values section under Total Power (dBm) in the PA Design Values subsection (see Section "2.5. Calculated Values—PA Design Values").

■ **Center Frequency (MHz)**: The RF frequency of operation; range is 27 to 960 MHz.

■ **Nominal Cap Word**: This is the nominal setting of the power amplifier output capacitance bank that is part of the antenna tuning circuit; range is 0 to 511.

■ **External Diff Cap (pF)**: This is an external capacitor placed across the TXP and TXM pins. Assuming this has a much larger quality factor than the on-chip capacitance bank, there may be antenna efficiency advantages of using this external component.

■ **Q-Factor External Cap**: This is the quality factor of the external capacitor. Typical values would be 250–300.

SILICON LABS

2.3. Calculated Values—Chip Impedance

The "Chip Impedance" fields of the calculator spreadsheet provide the impedances of a parallel RC equivalent of the chip; i.e., Real_Z is the value of the parallel equivalent R, while the Imag_Z is the impedance of the parallel equivalent C at the operation frequency. The result of the Imag_Z field takes into account the effects of any external capacitance the customer wants to add (External Diff Cap under Power Setup), bond wire inductance, bond wire resistance, package parasitic, and the PA itself (bond pads, device parasitic, etc). The Total Diff Cap (due to Chip + External Load) field shows the capacitance value corresponding to the Imag_Z value.

The value of the Real_Z and Imag_Z depend on the type of the package (MSOP or SOIC), frequency, and capacitance bank settings.

- **Total Diff Cap due to Chip + External Load (pF)**: The equivalent differential capacitance seen looking into the package pins. It includes the on-chip capacitance bank, the package capacitance, and the external differential capacitor (if used).
- **Real_Z (Ohms)**: The equivalent parallel resistance of the chip at the frequency of operation.
- **Imag_Z (Ohms)**: The equivalent parallel reactance of the chip at the frequency of operation. This value is always negative, indicating a capacitive reactance that can be seen when looking into the chip.
- **S11 Abs**: This is the absolute value of the reflection coefficient of the PA as seen from the chip terminals. It is calculated using the chip impedance values and assuming 50 Ω load impedance.
- **S11 Phase**: This is the phase (in Radians) of the reflection coefficient of the PA as seen from the chip terminals. It is calculated using the chip impedance values and assuming 50 Ω load impedance.

2.4. Calculated Values—Antenna Targets

The "Antenna Target" impedance fields of the calculator spreadsheet provide the impedances of a parallel RL equivalent of the optimum termination impedance, i.e., Real_Z is the value of the parallel equivalent R, while the Imag_Z is the impedance of the parallel equivalent L at the operation frequency.

The value of the Real_Z and Imag_Z of the Antenna Target depends on the Chip Impedance values and the power setting.

In the event of a high PA output power setting and high Real_Z value of the Chip Impedance, the Antenna Target impedance should limit the voltage magnitude to the allowed maximum value that prevents voltage clipping at the drain(s) of the PA devices. Thus, the Real_Z value of the Antenna Target impedance is lower than the Real_Z value of the Chip Impedance (i.e., the Q of the antenna is lower than the Q of the chip). This is the so-called voltage-limited operation mode of the 4012 PA. Also, due to the desired condition of parallel resonance, the Imag_Z value of the Antenna Target impedance is the negative of that in the Chip Impedance. As the Imag_Z value of the "Chip Impedance" is always negative (capacitive), the Imag_Z value of the "Antenna Target" is always positive (inductive). Thus the antenna should always appear as a parallel RL circuit.

In the event of low PA output power settings when the RF current magnitude is low and/or at high cap bank settings when the Real_Z value of the "Chip Impedance" is low, the maximum allowed voltage swing cannot be achieved even with a very high Q antenna. In this case, the 4012 PA is working in a current limited operation mode and the optimum "Antenna target" Real_Z is identical to that of the "Chip Impedance". The optimum "Antenna target" impedance is the complex conjugate of the "Chip Impedance" as if the voltage swing is not limited, which results in maximum power delivery to the antenna. A general rule is that the "Antenna target" Real_Z impedance is equal to or lower than the Real_Z value of the "Chip Impedance". More detailed description can be found in "AN369: Si4010 Antenna Interface and Matching Network Guide".

- **Real_Z (Ohms)**: The required parallel equivalent resistance of the antenna at the frequency of operation to meet the desired output power.
- **Imag_Z (Ohms)**: The required parallel equivalent reactance of the antenna at the frequency of operation to meet the desired output power. This value is always positive, indicating an inductive reactance seen looking into the antenna.
- **Power Dissipated in Antenna (dBm)**: The expected power delivered to the antenna. This value is always less than the Total PA Power (under "Power Amplifier Setup"), as some fraction of the total power is always

dissipated in the PA itself.

■ **Expected Radiated Power (dBm)**: The expected radiated power of the device given the specified antenna efficiency.

2.5. Calculated Values—PA Design Values

■ **Iout Target (mA)**: Theoretical output current that meets the power target.

■ **Total Power (dBm)**: The estimated output power based on all loss mechanisms. This is the sum of the power delivered to the antenna and the power dissipated in the PA itself. Except for quantization effects, this should be equal to the Total PA Power selected under "Power Amplifier Setup".

■ **Actual Iout (mA)**: The actual output current delivered to the antenna that accounts for quantization effects and chip losses.

■ **Max Diff Vpk at PA (V)**: The calculated peak differential voltage swing directly at the PA output (inside the chip). The calculator will always work to keep this peak differential voltage swing below a maximum level that would result in clipping of the drain waveform.

2.6. Commands—PROPERTY | PA_CONFIG

■ **PaMaxDrv**: Boost bias current to output DAC. Allows for maximum 11.5 mA drive. Only LSB bit (bit 0) is used.

■ **PaLevel**: PA transmit power level. Each step in bLevel corresponds to a 0.25 dB change in output current.

■ **PaCap**: Nominal setting of the PA capacitance bank.

■ **fAlphaSteps**: fAlpha is a parameter for temperature variation compensation of PA output power.

fAlphaSteps= (fAlpha+0.075) / 0.0006

More details can be found in Section "2.8. Calculating Temperature (fAlpha) and Antenna Reactance (fBeta) Compensation Parameters ".

■ **fBetaSteps**: fBeta is a parameter for antenna reactance variation compensation of PA output power.

fBetaSteps= (Beta+0.254) / 0.002

More details can be found in Section "2.8. Calculating Temperature (fAlpha) and Antenna Reactance (fBeta) Compensation Parameters ".

2.7. Usage of the Power Amplifier Setup

This part of the spreadsheet can be used in three different scenarios:

■ **Scenario 1**: The target antenna has been designed/measured/simulated, so its impedance and the target radiated power is known.

■ **Scenario 2**: The target antenna has been designed and its impedance is not known, but the target radiated power is known.

■ **Scenario 3**: Only the target radiated power is known; the antenna characteristics are required.

These scenarios will be discussed in detail in the following paragraphs:

Scenario 1:

The target antenna has been designed/measured/simulated, so its impedance and the target radiated power is known.

1. Set the desired frequency.
2. Set the desired total PA power (see notes below).
3. Select Yes for Manual impedance Entry.
4. Enter the antenna impedance (parallel equivalent resistance and reactance). The Antenna Imag(Z) parallel equivalent reactance must be a positive (inductive) value.
5. The spreadsheet calculates PaCap, PaLevel, and PaMaxDrv.
6. Verify the following:

■ Chip Impedance Imag_Z Entry: It should be the complex conjugate of the Antenna Imag(Z) entered in the

SILICON LABS

Antenna Setup. If not, it is because the antenna reactance falls outside the range of the PA.

◼ Command parameter PaCap:
- It should be between 0 and 511.
- It should fit into one of the ranges shown in Table 1, "Expected PaCap Values for Different Frequency Ranges," on page 6 based on the target operating frequency.
- If the obtained PaCap is 511, then an External Diff Cap is required.
- If the obtained PaCap is 0, then the antenna should be redesigned because the input capacitance of the PA exceeds the requirements of the antenna.

Notes:

1. The Total PA Power target can be estimated based on the expected efficiency of the loop antenna (generally between 1–15%) and the desired radiated power target. For instance, if 0 dBm radiated power is required and the loop antenna efficiency is 12.5%, then the Total PA Power is roughly 0 dBm $-10\log(0.125) + 0.8 = 9.8$ dBm. In the equation, the 0.8 dBm is simply an estimate for the losses that will be encountered in the PA itself and is a good rule of thumb for 300–500 MHz of operation. For higher frequencies, a loss estimate of 1–1.2 dB should be used.

2. Verify also that Max Diff Vpk at the PA does not exceed 3.5 V. If the Max Diff Vpk exceeds 3.5 V, then the driver begins to seriously clip and linear analysis breaks down.

3. Look at the settings for PaMaxDrv and PaLevel. If these are highlighted in purple, then the setting is as high as possible. This setting is acceptable unless the drive level needs to be adjusted to keep the power constant due to temperature or antenna reactance changes. If so, having the nominal drive level at maximum will not allow the PA to adjust the power upwards if required. For this case, it is a good idea to keep the nominal drive setting 4-6 steps below the maximum or above the minimum value to allow room for the power adjustment algorithms. If constant power is not required, fAlpha and fBeta will always be set to zero, and having the PaLevel at its maximum or minimum value is fine.

Scenario 2:

The target antenna has been designed and its impedance is not known, but the target radiated power is known.

1. Prototype the Si4012 board with the uncharacterized antenna and measure the radiated power.

2. Read out from the Si4012 the PaCAP setting with WDS, after TX.
   - It should be between 0 and 511.
   - It should fit into one of the ranges shown in Table 1.:Expected PaCap Values for Different Frequency Ranges based on the target operating frequency.
   - If the obtained PaCap is 511, then an External Diff Cap is required.
   - If the obtained PaCap is 0, then the antenna should be redesigned because the input capacitance of the PA exceeds the requirements of the antenna.

3. Do a number of experiments on radiated power vs. PaLevel setting. Adjust PaLevel until significant output compression is seen in the radiated power. Normally, the change in the output power is 0.25 dBm/LSB change in PaLevel. When this is no longer true, the PA is beginning to clip and the output swing at the PA is roughly 3.5 V peak. Record the PaLevel and PaMaxDrv settings where the gain compression begins to occur.

4. Change the Manual Impedance Entry to No.

5. Enter the PaCap setting (determined in step 2) into the Nominal Cap Word field.

6. Now the Real and Imag PA impedance values under Chip Impedance are available (equivalent parallel values).

7. Adjust the Total PA Power until the PaLevel and PaMaxDrv align with the settings determined in step 3.

8. Now the Real_Z and Imag_Z estimates of the antenna are available out of the spreadsheet (under Antenna Targets).

9. The Approximate Efficiency term under Antenna Setup can also be obtained by adjusting it to match the radiated power that was measured in step 1 with what is seen under Antenna Targets.

SILICON LABS

Scenario 3:

Only the target radiated power is known; the antenna characteristics are required.

1. Set the desired frequency.
2. Set the total PA power (see notes below).
4. Choose the Nominal Cap Word roughly based on Expected PaCap Values for Different Frequency Ranges.
5. The spreadsheet results provide the antenna characteristics for the given power target.

Notes:

1. The Total PA Power target can be estimated based on the expected efficiency of the loop antenna (generally between 1–15%) and the desired radiated power target. For instance, if 0 dBm radiated power is required and the loop antenna efficiency is 12.5%, then the Total PA Power is roughly 0 dBm–10log(0.125) + 0.8 = 9.8 dBm. In the equation, the 0.8 dBm is simply an estimate for the losses that will be encountered in the PA itself and is a good estimate for 300–500 MHz of operation. For higher frequencies, using an estimate of 1–1.2 dB may be a better guess.
2. The Calculator tries to keep the Max Diff Vpk at PA (under PA Design Values) always at 3.5 V because the antenna impedance will be chosen as large as possible to conserve PA current.

Table 1. Expected PaCap Values for Different Frequency Ranges

Frequency (MHz)	Expected PaCap Range
< 300	100–400
315	100–350
434	100–250
868	< 80
915	< 64

SILICON LABS

2.8. Calculating Temperature (fAlpha) and Antenna Reactance (fBeta) Compensation Parameters

2.8.1. fAlpha

Parameter for temperature variation compensation of the PA output power. If constant radiated power vs. temperature is desired, this constant may be used to let the radio compensate the PA drive strength as a function of temperature. It can be calculated by measuring the output power at different temperatures while Alpha is set to 0.

Example: Assume 1 dB change in 50 °C temperature variation. The PA output power is programmable in 0.25 dB steps, so 1 dB change is a 4-step variation in PA level setting (bLevel). Therefore, Alpha should be set to 4/50 = 0.08.

2.8.2. fBeta

Parameter for antenna reactance variation compensation of the PA output power. If constant radiated power vs. antenna reactance change (due to component variations or hand-effect issues) is desired, this constant may be used to let the radio compensate the PA drive level. fBeta is a small-signal parameter that automatically adjusts the PA drive level based on where the PA was tuned during the Pa Tune Process. In order for fBeta to function correctly, the expected value of PaCap must be known for the target system.

If the reactance of the antenna changes, the PA must also compensate to keep the system properly tuned. It is done by the Pa Tune Process. For instance, if the effective inductance in the antenna drops due to an increase in the antenna capacitance, the PA capacitance must increase to keep the resonance the same. Effectively, this drops the PA load resistance, lowers swing, and decreases radiated power. This effect is compensated by fBeta if it is provided in the PROPERTY | PA_CONFIG.

With an established antenna characteristic, the spreadsheet calculates fBeta by looking at the sensitivity of the total radiated power to the changes in the reactance of the antenna. Since fBeta represents a small-signal sensitivity, the calculation has to make an assumption about how much variation in reactance the antenna sees. Currently, the calculator assumes a ±15% shift.

Note: For a given target power and PaCap setting, the antenna impedance is adjusted to hit the power target and the fBeta is given based on these antenna and PA impedances for that power target. However, if less power is needed, and the current PA and antenna impedances are the same respectively, then only the PaLevel (PaMaxDrv) should be decreased, and the SAME fBeta would still apply because the sensitivity to changes in the antenna impedance have not changed. In other words, fBeta applies for a given PA and Antenna Impedance, independent of the PaLevel ultimately chosen.

3. Modulation and Data Rate Setup

The Modulation_FSKDEV and Bitrate_Config property setting commands can be set up here.

3.1. User Inputs—Bit Rate and Modulation Setup:

- **Bit (or Data) Rate (Kbits/s)**: This is the bit or data rate of the transmitter.
- **Modulation**: OOK or FSK.
- **FSK Deviation (kHz)**: This is the FSK frequency deviation of the output frequency in response to a data signal. It is equal to half of the frequency difference between the frequency of the logical zero and the frequency of the logical one.
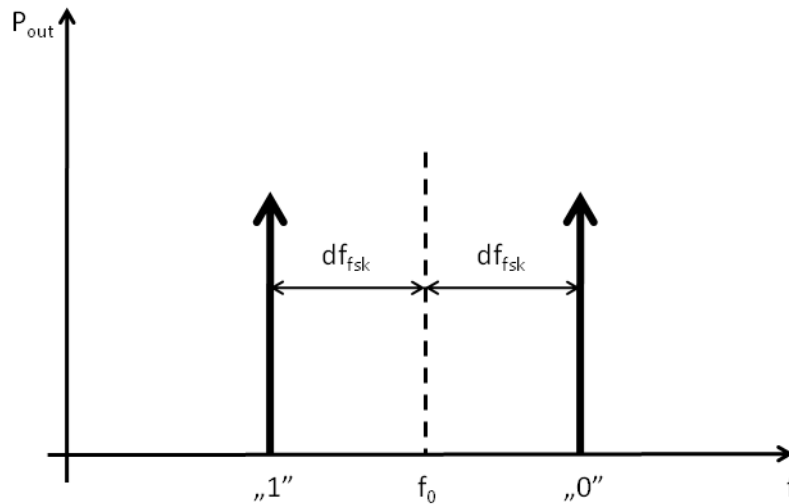

Figure 2.

- **Target Ramp Rate (µs)**: This parameter is the target ramp rate. Select 1,2,4 or 8 µs

3.2. Calculated Values—Bit Rate and Modulation:

- **Ramp Time (µs)**: The actual ramp time of turning on and off the PA.
- **Actual Symbol Rate (kbit/s)**: The actual symbol rate produced by the chip after taking into account quantization effects due to the timers.
- **Ramp Time/Symbol Rate**: The ratio of the ramp time divided by the symbol rate.
- **Expected FSK Deviation (kHz)**: The expected FSK deviation with quantization error.

3.3. Commands—PROPERTY | MODULATION_FSKDEV:

- **ModuType**: modulation type 0 = OOK or 1 = FSK
- **biFskDev**: calculated parameter for PROPERTY| MODULATION_FSKDEV

3.4. Commands—PROPERTY | BITRATE_CONFIG:

- **RampRate**: controls the PA edge rate
- **DataRate**: bit rate setting

4. Frequency Setting

Setting the target center frequency means simply issuing the Set Property | TX_FREQ Command with the correct parameter. The parameter for this command should be calculated as follows:

- **OOK mode**:

Frequency = desired center frequency

- **FSK mode**:

Frequency = desired center frequency + deviation

In other words, the frequency should be equal to the higher FSK frequency.

4.1. User Inputs—Frequency Setting

The desired target frequency should be set in the Power Amplifier Setup section of the spreadsheet (see Section "2.2. User Inputs—Power Amplifier Setup ").*

*Note: This value should always be the desired channel center frequency.

4.2. Commands—PROPERTY | TX_FREQ

In both FSK and OOK mode, the correct value of the Set Property | TX_FREQ Command can be obtained from the calculator.

5. Battery Life Calculation

The calculator also estimates battery life of a system given the packet setup and number of transmits per day. The inputs to the calculator are all of the above inputs plus the following:

5.1. User Inputs—Packet Setup

- **Number of Bits in Packet**: Number of bits in the packet excluding the preamble bits.
- **Preamble Bits**: Number of bits in the preamble.
- **Time Prior to Transmit (ms)**: The time required to boot the chip and send a packet out.
- **Number of Packets**: The number of packets sent out per button press.
- **Time Between Packets (ms)**: The time between repeating packets.
- **Transmits/Day**: The number of transmits per day.
- **Battery Capacity (mAh)**: The capacity of the desired battery in mAh.

5.2. Calculated Values—Battery Life

- **Avg Transmit Current (mA)**:The average transmit current.
- **Peak Transmit Current (mA)**: The peak transmit current.
- **Charge/Year (mAH)**: The charge per year in mAH.
- **Battery Life (Years)**: The estimated battery life of the specified battery.
- **Average Battery Current (µA)**: The average current drawn from the battery.

Simplicity Studio

One-click access to MCU tools, documentation, software, source code libraries & more. Available for Windows, Mac and Linux!

www.silabs.com/simplicity

MCU Portfolio
www.silabs.com/mcu

SW/HW
www.silabs.com/simplicity

Quality
www.silabs.com/quality

Support and Community
community.silabs.com

Silicon Laboratories Inc.
400 West Cesar Chavez
Austin, TX 78701
USA

http://www.silabs.com