Melexis
Microelectronic Integrated Systems

Applications Note
RF Transmitter and Antenna Design Hints

This application note covers the
TH7107,TH71071,TH71072,TH7108,TH71081,TH71082,TH72011,TH72031,TH7204
Single Frequency Transmitters. These transmitters have different features and cover different bands but they all have common features, which make them very easy to use for different applications.

Features common to all transmitters:

The most common feature of all the transmitters is that the output frequency is 32 times the reference frequency. In most cases, the reference will be a quartz crystal, but it could also be an external source connected to the RO1 pin.

The capacitance looking into the RO1 pin is approximately 15pF. Therefore the crystal should be specified to have a load capacitance of 15pF at the desired output frequency divided by 32. Thus, if the output frequency is 315MHz, the crystal would be 9.84375 MHz with a load capacitance of 15pF, and CX1 shown in the data sheet and EVB schematics could be omitted. The output frequency tolerance and drift with temperature depend only on the crystal since the VCO in the IC is always locked to exactly 32 times the crystal frequency.

If the transmitter is to be used to generate an FSK signal, the crystal can be specified for a load capacitance between 12 and 15pF. Then CX1 is selected so the series combination of CX1 and the internal 15pF tunes the reference oscillator on the high side of the center frequency and when CX2 is switched in, the reference oscillator will be on the low side of the center frequency. The greatest frequency deviation could be obtained if the crystal were specified to be series resonant at the center frequency with CX2 replaced with an inductor. The inductor would be selected to have 2 times the reactance of the 15pF in the IC.
Therefore, at 9.84375MHz, the inductor would be 34.8uH.

The maximum FSK data rate is determined by the frequency response of the PLL and the Q of the crystal oscillator circuit. However, the receiver parameters also limit the maximum FSK data rate, and in practice, it is around 40kbps. The values of the loop filter components, RF1 and CF1, can be adjusted to modify the transmitted FSK signal. The trade-off is between the shape of the FSK signal and the wide-band noise of the output signal. The loop is designed to have a wide bandwidth to suppress the wide-band phase noise of the internal oscillator.

ASK modulation is obtained by turning the transmitter output stage on and off. Since there are no time constants involved, the maximum data rate can be as high as 150kbps. This is limited by stray capacitances in the receiver and not by the transmitter. Note that if the transmitter is in the stand-by mode with everything off, it takes about 800uS for the reference oscillator to get going before data can be transmitted. This is due to the high Q of the crystal oscillator. Therefore, the microprocessor controlling the transmitter should first drive the ENTX pin high, wait about 1mS and then start sending data.

The ASK dynamic range of the output signal is over 60dB so the output is essentially OOK (on-off-keying)

One advantage of this is that the receiver to transmitter range over which the system will operate is very large, because even if the transmitter is close enough to overload the receiver, the off signal is so low that the data pulses are easily decoded.

The output power is determined by the voltage on the PS pin. There is an internal 20uA current source from Vcc to the PS pin so when the PS pin is open, the voltage is highest and the power output is highest. The output power is zero when the PS pin is below 190mV. If you assume 100mV for the off condition on the PS pin, the resistance would be $\frac{100\text{mV}}{20\text{uA}} = 5\text{K}$.

For the TH71*** series, the output power goes in 200mV steps starting at 200mV:

V_{PS}	relative output power	output stage current
$\leq$100mV	0 (no output)	0
300mV $\pm 20\text{mV}$	1	0.8mA
500mV	2	1.0mA
700mV	3	1.4mA
900mV	4	2.0mA
1.1V $\pm 100\text{mV}$	5	3.0mA
$\geq$1.3V	6 (maximum)	5.0mA

Therefore, for example, if a 4.7K resistor is connected from the PS pin to ground, and the modulation source is 3.3V, a resistance of 13K from the source to the PS pin will set the transmitter to power step 4.

The TH72*** series have 5 power steps with different voltages for the PS pin settings:

Vps	Pout in dBm
<.14V	<-70
.20 to .28V	-15
.40-.62V	-6
.75-1.15	0
>1.3V	+6

The data sheets for the TH72*** series show them to be an FSK transmitter, but they can be used in the ASK mode by simply modulating the PS pin as with the TH71*** types.

Features specific to each type of transmitter:

The TH7107 and TH7108 have the most features and the most pins. However, since these ICs are packaged in the SSOP16 package, the package size is the same as the SO8 of the other ones.

The ENCK and ENTX modes are defined in the data sheet. One important consideration when using the CKOUT pin (pin8) is to keep its traces away from the crystal oscillator traces. If this is not done, the stray coupling will modulate the crystal oscillator and sidebands spaced at the clock out frequency will appear on either side of the output signal. At 315MHz, signals at 315 +/-2.46 MHz will be present.

The CKOUT signal can be used for purposes other than a clock signal for a microprocessor. For example, it can drive a programmable divider to produce tones for modulating the transmitter.

The TH71071 and TH71081 are in an 8 pin package and are just ASK transmitters with very few external parts. They have a balanced output for driving loop antennas. The TH71072 and TH71082 have a single ended RF output and a CKOUT which is ¼ the crystal frequency.

The TH72011, TH72031 also are in an 8 pin package, have a single ended RF output. These require fewer external parts because the loop filter is internal. They also have more output than the TH71*** series, and can produce either ASK or FSK output signals. Another feature of these ICs is that they operate down to 1.9V and over a temperature range of –40C to 125C.

Crystal selection:

If the transmitter is to be used for only ASK, the crystal can be specified for a load capacitance of 15pF and connected from the RO pin to ground without any additional capacitor. The internal capacitance of the IC will provide the load capacitance for the crystal.

If the crystal is specified with a load capacitance of 10pF, the circuit in figure 1 will give a peak-to-peak frequency deviation of about 60KHz at an output frequency of 315MHz. The 1nF capacitor should be an NPO type and is there only to keep the DC voltage off the crystal.

Fig 1

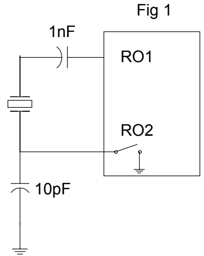
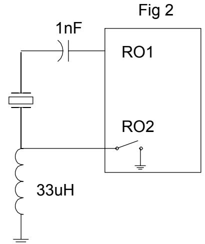


Fig 2



If really wide deviation is desired, the 10pF can be replaced with an inductor as shown in fig 2. In this case, specify the crystal to be series resonant at the desired frequency. When the internal switch is closed, the crystal is loaded with the 15pF in the IC, and when it is open, it is loaded with the series combination of the inductor and the internal 15pF. The inductor is chosen so its reactance is 2 times that of 15pFat the crystal operating frequency.

If it is important that the center of the FSK signal be at the center of the channel, the following equations can be used to specify the crystal:

f_0 = the desired center frequency when loaded with C_L
C1 = the motional capacitance of the crystal (very small)
C_0 = the shunt capacitance of the crystal (usually around 5.0pF)
C_L = the load capacitance on the crystal at the center frequency

First calculate the series resonant frequency of the crystal: [1]

$$f_s = f_0\left[1-\left(\frac{.5C_1}{C_0+C_L}\right)\right]$$

Using this equation, calculate $f_{Load\ 1}$, the frequency with the switch closed so the load capacitor is 15pF:

$$f_{Load1} = \frac{f_s}{\left[1-\left(\frac{.5C_1}{C_0+15pF}\right)\right]}$$

Now calculate the required C_L to give the same frequency on the other side of the center:
$f_{load2} = 2f_0 - f_{load1}$

$$C_L = \frac{.5C_1 f_{load2}}{f_{load2} - f_s} - C_0$$

C_L is now equal to the series combination of the internal 15pF and CX2. If CX2 comes out to be negative, symmetry cannot be achieved with a capacitor load. In this case a coil could be substituted or a bit of unsymmetrical deviation must be allowed. If C_L is close to 15pF, CX2 may be too small, and the oscillator may stop running. Remember that the greatest deviation is obtained with a crystal specified for the smallest load capacitance but the frequency stability in this case is the worst. However, frequency stability is usually not a problem in a wide-band system like this, so it is usually better to get the most deviation to obtain the best signal-to-noise improvement with FSK.

Note that the greatest deviation can be obtained using crystals with the smallest load capacitance, but the frequency stability will be the worst.

[1] Louis Bradshaw, "Frequency Pullability in AT Cut Crystals",ECN May 15,2001

Another crystal specification is necessary when the transmitter is used in FSK applications. Then the spurious responses of the crystal near the operating frequency is important; it must be more than 20dB below the main response within 1MHz of the center frequency. If the 20dB spurious response limit is exceeded, the FSK spectrum will have spurious outputs outside the modulation bandwidth. Under these circumstances, especially at data rates larger than 5kbps, the demodulated signal in the FSK receiver can be distorted.

Antenna design:

If a loop antenna as part of the PCB is used, the loop is just a big coil, and the following design equations are useful:
The inductance of a small rectangular loop is given by. [2] (all dimensions in Meters)

$$L = \frac{\mu_0}{\pi}\left[b \times \ln\left(\frac{2A}{.5 \times w(b+c)}\right) + a \times \ln\left(\frac{2A}{.5 \times w(a+c)}\right) + 2(.5 \times w + c - a - b)\right]$$

a = length of one side of the loop b = length of the other side of the loop

$c = \sqrt{a^2 + b^2}$ $A = a \times b$ $\mu_0 = 1.26 \times 10^{-6}$ w = trace width

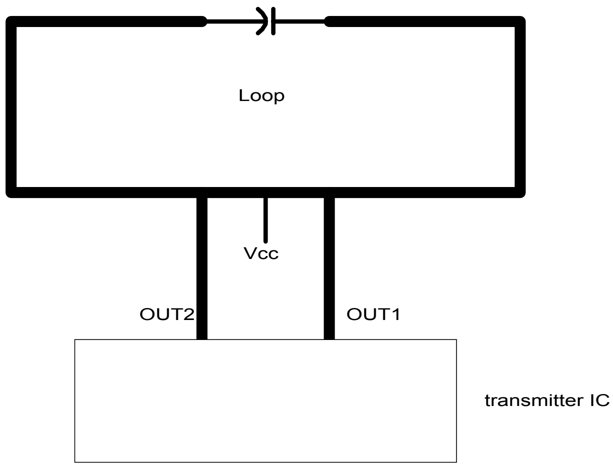
If the loop is made too large, you will not be able to tune it with a reasonable sized capacitor. The Melexis transmitter ICs have sufficient output to exceed most radiation limits without using the largest possible loop, so it is better to make the loop a little smaller so it is easier to tune.

The impedance of the loop will always be much larger than necessary to match the transmitter output which is around 200 Ohms, so some method of tapping it needs to be used. One way is to use a relatively large capacitor across the output collectors and then tune the loop with a smaller capacitor like the arrangement in the evaluation boards. This requires that the DC current to the output collectors be supplied through inductors as is done in the evaluation boards. Another lower cost method is to supply Vcc to the loop at the center and connect the output collectors to tapping points on the loop as is shown in Fig 3.

With this arrangement, the loop Q will be higher than when using two tuning capacitors, so it may be desirable to use a trimmer to tune the loop or to reduce the loop Q slightly with a resistor across a fixed tuning capacitor. This will reduce the variation in output level with tolerance variation in the tuning capacitor.

[2] Fujimoto,Henderson,Hirasawa,James, "Small Antennas", John Wiley & Sons

Fig 3



Some experimentation with the tap positions will be needed to get the desired output power. If the transmitter is first set to its maximum output power, the taps can be adjusted to achieve the maximum radiated field strength. Then the power can be reduced to meet the field strength limits. Since the Melexis receivers have an RSSI output with a large dynamic range, they can be used to measure the relative field strength by placing one at a fixed distance from the transmitter being worked on. Connect a voltmeter to the RSSI output and observe the level while changing the antenna taps. Since changing the taps may change the loop tuning slightly, the tuning capacitor should be made variable so the output can be peaked.

The tap positions can also be calculated if the loaded Q of the antenna is known. This is somewhat difficult to determine accurately, but if a resistor across the tuning capacitor is used to reduce the loop Q, it can be more accurately determined. With a single tuning capacitor, the loop Q will usually be around 300 to 500, so if a resistor is added to produce a loaded Q of 50 to 100, the unloaded impedance will not affect the loaded impedance very much.

Assuming an unloaded Q, calculate the tuned circuit impedance, R_p: $R_p = Q_o \times 2\pi f \times L$

The load resistor to produce a loaded Q_L is: $R_{EXT} = R_p\left(\frac{Q_L}{Q_o - Q_L}\right)$

Calculate a new R_p using the above equation with Q_L substituted for Q_o.

The distance between the taps can now be calculated based on the square root of the ratio between R_p and the desired load on the transmitter IC.

$$\frac{\text{total loop length}}{\text{distance between taps}} = \sqrt{\frac{R_p}{R_L}}$$

Where R_L is the load presented to the transmitter IC,

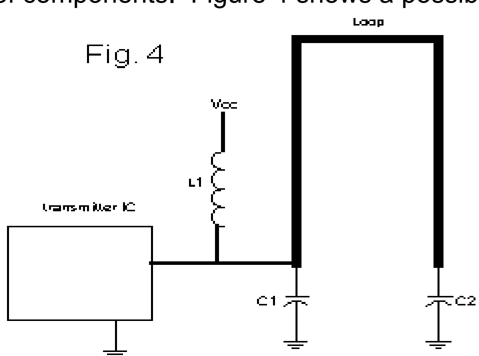
Since the loop is a high Q tuned circuit, it will suppress the harmonics of the output so the transmitter should easily meet the requirements for harmonic levels. However, one precaution which should be taken is to keep the loop traces away from other traces on the PCB. Capacitive coupling between the loop and other traces will couple the harmonics better than the fundamental, and the other traces may turn out to be the right length to resonate at one of the harmonic frequencies.

Monopole or other antennas can be used with transmitters such as the single-ended TH71072, TH71082, TH72011, TH72031 and TH7204.

If the antenna is electrically short (less than ¼ wavelength), the radiation resistance will be low unless a helical antenna is used, so a matching network between the transmitter and antenna will be needed. The losses of the matching network will be significant unless a relatively large air coil is used, and the harmonic levels will not be suppressed as much as with a loop.

Single ended output transmitters can also be matched to a loop antenna by tapping the loop or using a matching network. In this case, the matching network is a little easier to adjust and uses about the same number of components. Figure 4 shows a possible circuit:

Fig. 4



L1 just supplies the collector voltage for the output stage and is relatively large. For 314 to 433MHz 100 to 220nH is ok. C1 is set to give the desired load on the output stage. For the TH70211 and TH72031 transmitter, the load should be around 300 Ohms. C2 can then be used to tune the loop.

TH71*** series PLL design information

The internal phase detector current is 300uA, so K_d for all the transmitters is

$$\frac{300\mu A}{2\pi} = 47.75\mu A/\text{radian}$$

The VCO constant varies with tuning voltage and the frequency band. The tuning voltage range is 0.6 to 2.0 Volts and the maximum slope is at the center of the range at 1.3V. The slope is somewhat less at the ends of the range. At 1.3V, the oscillator constant is:

At 400MHz, $K_o = 300\text{MHz}/\text{V} \times 2\pi = 1.88 \times 10^9 \text{radians}/\text{sec}/\text{V}$

At 900MHz, $K_o = 350\text{MHz}/\text{V} \times 2\pi = 2.20 \times 10^9 \text{radians}/\text{sec}/\text{V}$

The values shown in the data sheet were selected to give a good compromise between suppression of VCO noise and FSK modulation bandwidth, but other values can be calculated using the commonly available PLL design equations.

The TH72*** series of transmitters have the loop filter inside the IC so it cannot be changed.

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