Usage of the TDK51xx/TDA71xx transmitters in the 868 MHz ISM band

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Table 1

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1 Introduction

This Application Note gives a systematic overview of the aspects which have to be taken in account during the design of radio systems based on Infineon Technologies TDK5110; TDA7110; TDK5116F; TDA7116F transmitter chips, operating in the 868 MHz ISM band in order to maintain compliance with the regulatory requirements of the ETSI EN 300-220 standard.

As demonstrated later in **Chapter 2 Modulation parameters and their influence on signal spectrum**, if amplitude shift keying (ASK) is used as modulation method, a series of side-tones occur, grouped symmetrically around the carrier (i.e. in both the lower and the upper sideband).

Beyond the 1st tone ($f_c \pm f_m$) which falls always in the band, the 3rd tone ($f_c \pm 3*f_m$) is likely to be contained as well. By setting the modulation depth close to 100% (which is the case if ON/ OFF keying (OOK) is used, and this is way the TDK51xx/TDA71xx transmitters operate), the 5th overtone ($f_c \pm 5*f_m$) may fall also in the band, assuming the tests are conducted as defined per ETSI EN 300-220 standard.

Note: f_c denotes the channel frequency (carrier) and f_m the equivalent modulation frequency applied to the transmitter's data input (either the amplitude or the frequency modulation input).

The resulting occupied bandwidth (OBW) is therefore at least six- or even ten times the value of the equivalent modulation frequency (f_m) and sometimes this is rather a theoretical limit.

Explanations on the interdependencies between modulation (signal) parameters and their influence on the generated RF-signal spectrum are dealt with in the **Chapter 2 Modulation parameters and their influence on signal spectrum**. This is an important aspect as far as the radiated signals must comply with regulatory standards in terms of frequency stability, maximum radiated RF power, occupied bandwidth, maxima of unwanted radiations (i.e. harmonics of the carrier, intermodulation products, RF power leaking into adjacent channels and so on).

Beyond mandatory fulfillment of regulatory requirements those parameters (of the transmitter) also have high importance for establishment of well performing and efficient radio links.

Chapter 3 Design hints and solutions is mainly a list of hints and measures which have to be kept in mind during transmitter design process. Cost-efficient signal shaping and power ramping solutions are listed and some performance predictions are made in this part of the document. The material focuses mainly on systems employing amplitude shift keying (ASK). The potential risk of emission-mask violation is higher if this modulation scheme is used versus the other popular and wide-spread method, the frequency shift keying (FSK).

Main goal of listed solutions is to:

- minimize the spectral splatter (caused mainly by transients with fast rise- and falling edges)
- avoidance of higher order sidetones, especially those with high-levels, as those may contribute to increase of the occupied bandwidth
- list of cost-effective signal shaping and power ramping solutions in order to reduce spectral splatter, occupied bandwidth and at some extent even the level of intermodulation products

The listed solutions applied as stand alone measures or as combinations of several methods are aimed toward maintaining compliance with the ETSI EN 300-220 regulatory standards.

As emphasized before, special attention is paid to the 868 MHz ISM band in this material.

1.1 Brief overview of the ETSI EN 300-220 requirements for 868 MHz ISM band

The spectrum mask, as defined by recent ETSI EN 300-220 regulation is shown in **Figure 1** and the limits are summarized in **Table 2**.

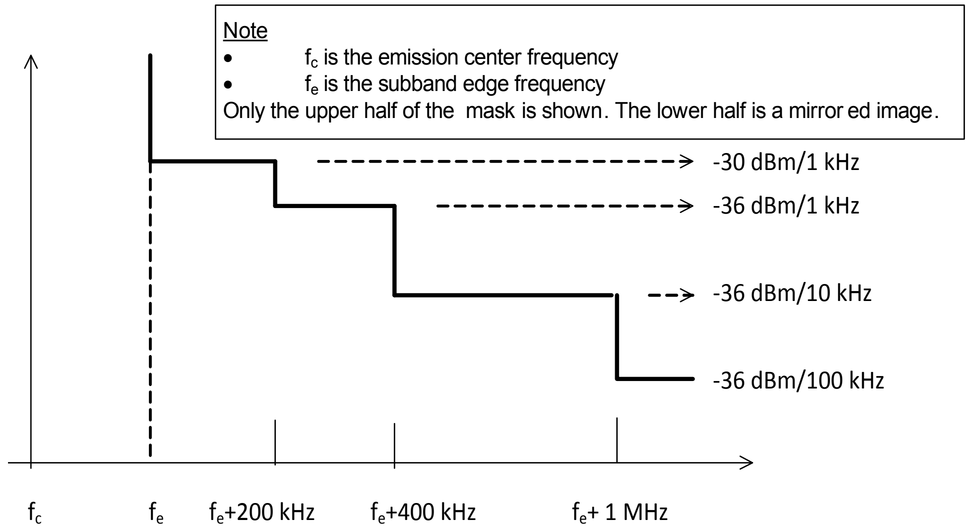

Figure 1 ETSI EN 300 220 spectrum mask for the 868 MHz ISM band

The mentioned standard defines the test methods, which are based on gradual increase of the resolution bandwidth (RBW) by increasing offsets relative to band center (i.e. as far from center, as wider the RBW). According to an additional clause, the measurements have to be performed with the recording instrument's detector set in maximum hold mode (MaxHold), which yields detector readings theoretically 9 dB, practically 10 dB over the RMS value reading (i.e. Peak = RMS + 9 dB).

In order to avoid the saturation of the recording instrument's input stage (usually the mixer in a spectrum analyzer) concise values for attenuator settings are listed within ETSI test description.

By small offsets from band center high attenuation is used, and the value is decreasing in 3 steps from 50 dB down to 10 dB by higher frequency offsets.

Note: The recording and measuring instrument used during the tests is usually a spectrum analyzer.

Table 2

Test case #	Start frequency [MHz]	Start frequency [MHz]	RBW [kHz]	VBW [kHz]	Attenuator [dB]	Mask limit [dBm]
-4	850	867.7	100	300	10	-36
-3	867.7	868.3	10	30	30	-36
-2	868.3	868.5	1	3	50	-36
-1	868.5	868.7	1	3	50	-30
1	869.2	869.4	1	3	50	-30
2	869.4	869.6	1	3	50	-36
3	869.6	870.2	10	30	30	-36
4	870.2	890	100	300	10	-36

The main factors which are influencing the occupied bandwidth are:

- data rate and encoding method of the digital signal, applied to transmitter, yielding an equivalent modulation frequency (f_m). In fact the input signal may be regarded as the sum of a fundamental frequency and its harmonics (overtones). The amplitude and phase of each elementary component is derived from decomposition into Fourier-series.
- modulation depth
- phasenoise, resulting from contribution of:
  - VCO itself
  - jitter and noise generated by the synthesizer's phase comparator and chargepumps
  - noise injection from supply /regulator and/ or ground loop couplings
  - synthesizer's loop filter response has a significant influence on the distribution function of the system, and consequently on the system's global phase noise figures
- unwanted components resulting from crosstalk (for example coupling from clock and/or Host GPIO lines into the PLL's subcircuits)
- spurs originating from Reference Oscillator (upmixing products in RF spectrum)
- VCO leakage (i.e. a tiny amount of RF energy from VCO may leak through the RF power amplifier even during the time this being in OFF state. The isolation of a not powered amplifier is high, but not infinite and RF leakage may be taken in account. If ASK modulation were used, the PLL is maintained in active state and locked on the transmit channel frequency. The amplitude modulation (or ON/ OFF keying, OOK) is achieved at the RF power amplifier level (as shown by **Figure 7**).

Finally two factors with high impact on computation and measurement of occupied bandwidth are:

- required output power (usually imposed by radiated power target figures of the transmitter and link budget)
- modulation method (ASK or FSK in case of the TDA71xx/TDK51xx transmitters). Quite often modulation scheme is imposed by compatibility considerations with already existing systems, in other cases the designer is free to make the choice.

It is worth to mention that the harmonic content of the generated RF signal (i.e. 2nd, 3rd, 4th.. Nth harmonics) is closely related to the transfer function of the matching network placed between the RF power amplifier's output and the load (this last is usually an antenna or array of radiators).

Present material does not deal in detail with the topology of the matching networks. Still it have to be emphasized that the EN 300-220 regulations set clear limits for maximum power level of unwanted emissions (sometimes also referred as out of band signals).

Emissions on harmonics of the allocated channel frequency fall in the category of unintentional signals.

1.2 TDK5110; TDA7110; TDK5116F; TDA7116F overview and features

The members of the TDK51xx/ TDA71xx transmitter family offer a high level of integration and need only a few external components in order to implement a fully functional transmitter. The device contains an integrated PLL synthesizer and a high efficiency power amplifier, which drives the load, in most cases a radiator (antenna). A special circuit design and a unique power amplifier design are used for reduced current consumption thus extending battery life.
Additional features are a power down mode (with very low quiescent current) and a divided clock output.

Main features

- Transmit frequency band 434/868 MHz (TDA7110; TDA5110) or 868 MHz (TDA7116F; TDA5116F)
- User selectable ASK and FSK modulation modes
- High efficiency RF power amplifier (typically +10 dBm RF output power)
- Low supply current
- Power down mode with low quiescent current (typical 0.3 nA @ +25°C current consumption in this mode)
- Crystal oscillator for accurate reference frequency generation
- Fully integrated PLL frequency synthesizer
- Clock output for µC clocking / synchronisation (clock output frequency is $f_{crystal}$ /16)
- On-chip VCO without any external components

- Chip-internal f_{TX_LOW} / f_{TX_HIGH} switch for FSK modulation mode
- Low external component count
- Supply voltage range [2.1.. 4.0] V
- Operating temperature range [-40.. +125] °C (TDK51xx series) and [-40.. +85] °C (TDA71xx series)

2 Modulation parameters and their influence on signal spectrum

Below is an overview of the major factors which influence the RF signal quality and spectrum, with emphasis on the parameters which are under the control of the System Designer and Programming Expert. Any knowledge on the relations between parameters which are influencing the signal quality, spectrum and resulting occupied bandwidth may be helpful when performing system design and during firmware development. Of course the tasks do converge toward systems which are compliant with regulatory standards and, at the same time are cost effective.

If the transmitter is part of an already given system (with predefined transmission parameters), the modulation and timing parameters are usually given (a priori) and there is little room for change. Nevertheless, even if the modulation type is imposed (ASK or FSK), certain parameters, which can potentially be influenced by design including circuit topology, layout and component value, may have a major impact on regulatory compliance by means of signal spectrum and occupied bandwidth.

2.1 Amplitude shift keying (ASK)

An amplitude modulated signal can be described in time domain as:

$$f(t) = A_c \sin(\omega_c t + \varphi) \times \left(\sum_j A_{mj} \sin(\omega_m t + \theta_m) \right) \quad (1)$$

where A_c is the amplitude of the carrier signal and $A_m j$ the amplitude of the modulation signal components.

The modulated signal contains frequency components (denoted tones) which are grouped at multiples of the modulation frequency and centered relative to (around) the f_c carrier frequency as shown in **Figure 2**.
The frequency of those tones, grouped around the carrier is $f_{tj} = (f_c \pm j^* f_m)$ where f_m is the modulation frequency and j is the order of the tone. These f_{tj} components are denoted also as sideband components, respectively in upper- and lower sideband (USB; LSB), relative to the carrier's frequency (upper sideband if $f_{tj} > f_c$ and lower sideband if $f_{tj} < f_c$).
If the modulating signal is a symmetrical one (for instance a square wave with 50% duty cycle) and if the RF power amplifier is switched on- and off to achieve amplitude modulation of the carrier (i.e. ON/ OFF keying, referred also as OOK) the spectrum of the modulated carrier contains the odd-order modulation tones, as dominants in the upper and lower sidebands.
In other words the energy of the modulated RF-signal is expected to be grouped mainly around the $f_{tj} = [f_c \pm (2j+1)^* f_m]$ spectral lines and significantly lower energy in the region of the even-order tones of $f_{tj} = [f_c \pm 2j^* f_m]$ frequency shall be expected.

Actually, as both the upper- and lower sidebands are included, this means that the occupied bandwidth (OBW) of an amplitude modulated signal, with modulation depth close to 100% (i.e. generated by switching the RF power amplifier itself or its driver stage ON and OFF) will always be at least twice the equivalent modulation frequency (OBW > 2 f_m).

Note: it is also possible to transmit only one "half" of the spectrum, either the upper- or the lower sideband, if a modulator with special architecture is set up for generation of single-sideband (SSB) signals. Either the upper- or the lower sideband is applied to the RF power amplifier (which shall have a reasonably linear transfer function) whereas the other sideband is rejected. The result is a reduction of the occupied bandwidth and, at the same time, an increase of the energy density in the radiated sideband.
The only drawback of the method is that at the Rx side the regeneration of the suppressed carrier is required for demodulation, which leads to a more complex demodulator structure of the receiver.

If the occupied bandwidth is computed on the inclusion criteria of all the spectral components -20dB below the carrier power (or in-band peak), the 3rd order sideband tones of OOK modulated signal will also be part of this

range. Thus, for a given f_m equivalent modulation frequency, the expected value of the occupied bandwidth (OBW) will be as follows:

$$OBW \geq 6 \times f_m \tag{2}$$

As an exemplification for above statements, two spectral plots are represented in **Figure 2**. The blue trace matches a signal spectrum generated by a square-wave modulating signal and a modulation depth close to 100% (i.e. similar to the ON / OFF keying method, referred also as OOK). The signal generator used for this test fulfills the instrument-grade specifications (i.e. a high-end generator have been used, instead of a TDK51xx/TDA71xx, just to show the limitations, which are very close to the theoretical ones).

The green plot corresponds to the same modulating signal, but with modulation depth reduced to 30%. The signals shown in this example have been generated by a highly accurate RF-signal generator with programmable AM modulation depth. The demonstration has been accomplished in order to emphasize the theoretical limitations bound to the occurrence of sidetones and occupied bandwidth.

By comparing the two plots, following conclusions are worth to be remembered:

- if the modulation signal is of a symmetrical waveform, then besides the carrier (f_c) the spectrum is dominated by the odd order sidetones $(2n+1)*f_m$ of the modulating frequency (f_m)
- the even order sidetones $(2n)*f_m$ of the modulating frequency (f_m) decrease rapidly by decreasing modulation depth (observe the blue vs. green plot, especially in the region of the 2nd sidetones)
- if the *-20 dB below peak* criteria is applied and if the modulation method is the ON/ OFF keying, then the 3rd order sidetone will fall into the occupied bandwidth
  (observe the two horizontal red lines, one set to carrier peak power and the other -20 dB below)

Note: the other main factor influencing the occupied bandwidth (OBW) is the modulation frequency (f_m), but this, respectively the datarate and encoding method are usually fixed per system definition.

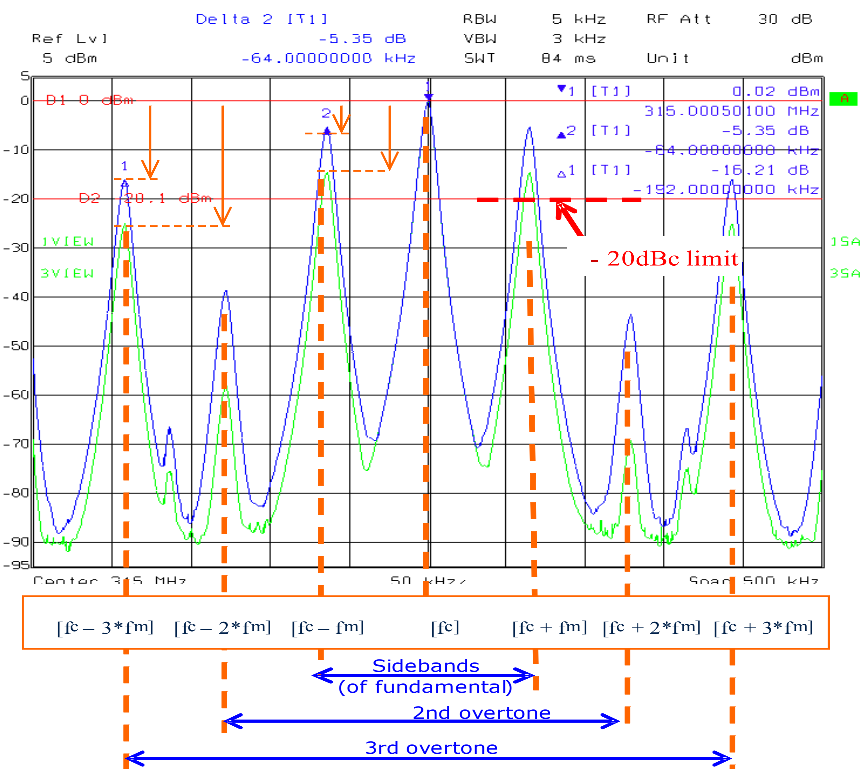

Figure 2 Sideband tones of an AM signal

The AM-modulator in TDK51xx/ TDA71xx uses the ON/ OFF keying method (at RF power amplifier level), yielding a modulation depth close to 100%. Assuming that ASK modulation is used, the only way to influence the bandwidth and spectrum of the generated RF signal is the ramping of the modulating signal (i.e. a slight decrease of slew-rate and the "rounding" of the leading and trailing edges of the waveform applied to the ASKDATA pin).

The states of the AM modulator of TDK51xx/ TDA71xx chips are summarized below:

Table 3 ASKDTA - RF power amplifier

ASKDTA	RF power amplifier
Low[1)]	OFF
Open[2)], High[3)]	ON

1) Low: Voltage at pin < 0.5 V
2) Open: Pin open
3) High: Voltage at pin > 1.5 V

Conclusion

- Judging solely on the usage of the occupied bandwidth criteria of a moderate modulation depth, it seems to have a clear advantage versus the ON/ OFF keying method. However, it is worthwhile remembering that if the modulation depth is reduced, the RF-power amplifier will be never be switched off during transmission, thus reducing the efficiency of the DC power usage of the transmitter. Meanwhile, on the receive side, decrease of the peak-to-peak voltage swing on the detector will produce detrimental effects on the data slicer, with potential degradation of the signal-to-noise ratio (S/N).
- However if there is a strong demand for reduction of occupied bandwidth, and the modulation method is AM (ASK) then consider setting the modulation depth to around 70..80%, which might reduce the 3rd order sidetone below the -20 dBc threshold, without significant efficiency degradation.
  Hints regarding some feasible solutions are contained in **Reference [2]** and in **Chapter 3 Design hints and solutions**.

An efficient way of reducing the spectral splatter caused by the transients (mainly during OFF-ON switching transitions of the RF power amplifier) is the ASK sloping capability.This means that a ramped signal, with moderate slew-rate shall be applied to the modulator (ASKDATA pin) instead of switching ON of the PA by a step-like, digital signal. **Figure 3** illustrates the difference in spectral energy distribution between two signals with same nominal power and datarate, both of the aforementioned being generated by ASK modulation. It is clearly visible that provided the use of the power sloping option, the power leaking into adjacent channels shall be significantly lower for the sloped signal towards the 5th order sidetone. In other words, the power sloped ASK signal will generate less interference at frequency offsets larger than [$f_c \pm 3*f_m$] than the unsloped signal.

Another highly effective measure against spectral splatter is the usage of power ramping. In this case the supply voltage of the RF power amplifier is gradually increased- and decreased, as shown in **Figure 16** and **Figure 15**.

In order to reduce the spectral splatter, it is recommended to implement either modulating signal sloping (i.e. the simplest solution, suitable for low and medium data rates) or power ramping (which assumes a few more external components, but it is more effective for medium and high data rates) in ASK applications.

Please consider the items enlisted below:

- A steep rise of the RF power does cause spectral splatter. This is not a chip issue, it is merely a consequence of physical laws.
  The steeper the transition (i.e. as shorter the rise time) the wider the expected bandwidth of the transient.
- Controlled rise of the signal power with moderate slew-rate in case of AM modulation may lead to a moderate increase of jitter by edge detection (in receiver). However, provided the edge detection and window positioning of expected phase transition are handled properly (by Firmware in Host, which will process the received raw

data) there will be no sensitivity loss (or just an insignificant degree) on the receive side and, at the same time out-of-band signals (spectral splatter, due to transients) are efficiently minimized on the transmit side.
- As rule of thumb, a moderate ratio (of around 10%) of power sloping is recommended.

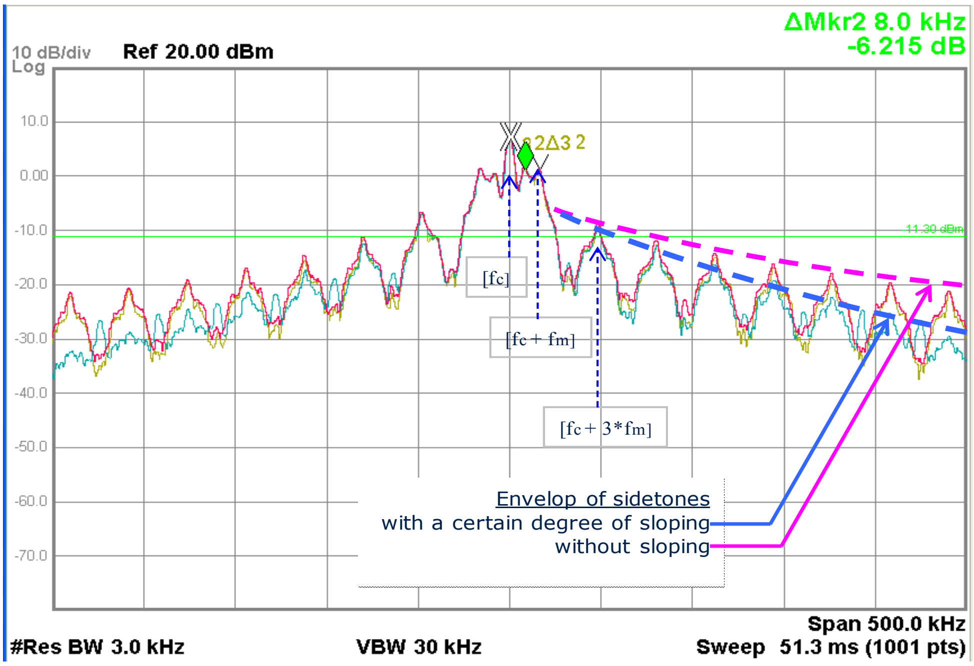

Figure 3 Level of sidebands, ASK signal with and without power ramping

The example shown in **Figure 4** depicts (from left to right) the time domain plot of an unsloped signal, generated by TDA7116F in ASK mode (left side plot), a signal sloped with 10% of bit duration (middle), and a signal sloped with 30% on the right side.

Note: the vertical axis of ***Figure 4*** *corresponds to a logarithmic scale (with 10 dB/div).*

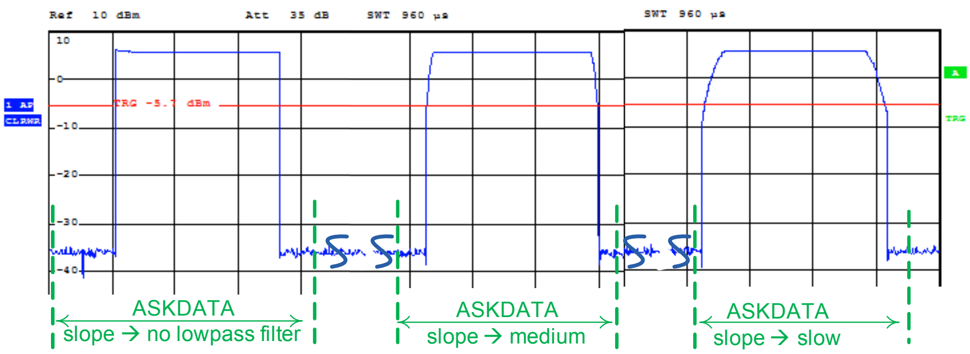

Figure 4 Effect of sloping on signal power (RF-power vs. time, vertical scale logarithmic)

A simple method for checking the effectiveness of RF-power sloping in terms of spectral splatter is the following:

- Set the center frequency of a spectrum analyzer to carrier frequency of the investigated transmitter.
- Set the frequency span to around 10..15MHz (or both the *Start* and *Stop* frequencies, as their difference yields the *Span*)
- Set the resolution bandwidth (RBW) of the instrument to around 100 kHz (100 kHz is fine for low and medium datarates, higher transmission speeds may require wider RBW)
- Set the video bandwidth to at least 3 times the RBW, to avoid distortion of the detected pulses
- Set a reasonably long sweep time, peak detector mode and maximum hold for the respective trace (MaxHold).
- Observe the "spikes" left and right of the carrier, caused by the RF-power transients (mainly caused by the OFF-->ON transition of the RF carrier). As long as the instrument is in MaxHold mode, from time to time start

a new Clear & Record (Write) operation may prove useful, to clear the recorded trace and start a new acquisition.

Recording more traces with the method described and at the same time varying the sloping ratio (the time constant, imposed by *C6* and *R3* of **Figure 12** can deliver quick (but coarse) indication about the effectiveness of a particular setup regarding the maxima of the transients.

The procedure is exemplified in **Figure 5**. In this example the transients in the signal with 10% slope ratio are associated, obviously, with lower amount of spectral splatter as signal generated without sloping control.
For accurate measurements instead of the quick-check described above the method as described in the particular *Regulatory Specification* should be used, of course (as per ETSI EN 220-300 for instance).

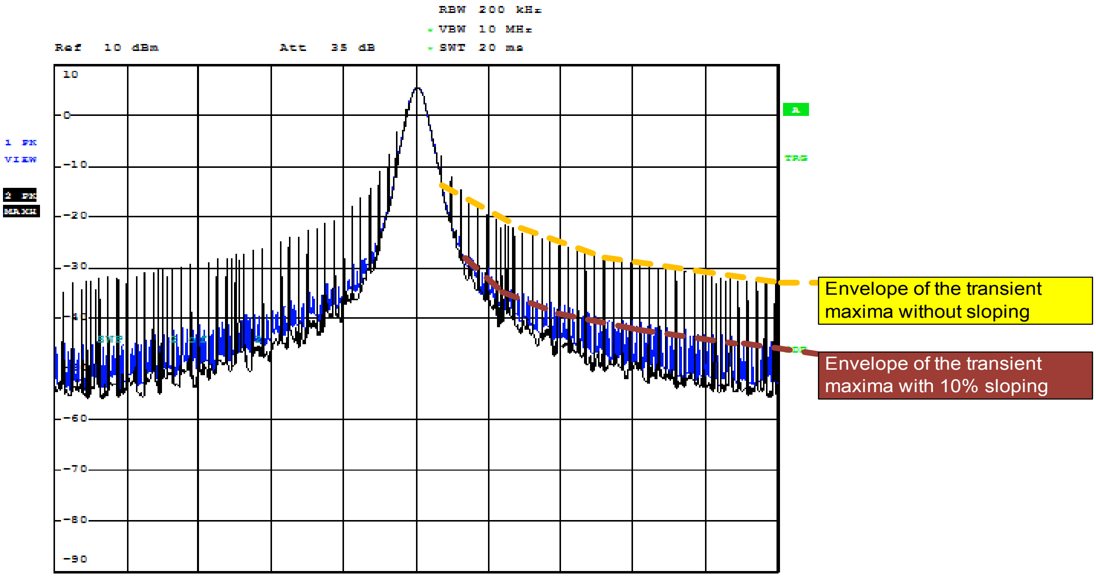

Figure 5 Effect of RF-power sloping on the transients

2.2 Frequency shift keying (FSK)

FSK modulation is achieved by detuning the reference oscillator frequency by a fixed amount. As shown in **Figure 11**, an external capacitor, connected in series with the crystal is either grounded by a chip- internal switch, or if the switch is left open, then the capacitor appears as connected in series with the crystal.

As it can be observed in this figure, the common node of the crystal and frequency-tuning external capacitor is connected over the FSKOUT pin to an internal switch, which at its turn is controlled by the state of the FSK modulator input (i.e. the signal level applied to FSKDTA pin).

The states of the FSK switch are summarized below:

Table 4 FSKDTA - FSK switch

FSKDTA (Pin7)	FSK switch
Low[1)]	CLOSED
Open[2)], High[3)]	OPEN

1) Low: Voltage at pin < 0.5 V
2) Open: Pin open
3) High: Voltage at pin > 1.5 V

The crystal oscillator operates

- at around 13.577 MHz if the carrier is centered in the mid of the 868 MHz ISM band (868.95 MHz) as the crystal frequency is 1/64 of the carrier frequency f_c, or

- at around 13.56 MHz if the carrier is centered in the mid of the 433 MHz ISM band (433.92 MHz) as in this case the crystal frequency is 1/32 of the carrier frequency f_c.

The signal generated by the reference oscillator is applied over buffers to the phase comparator and to a 1:16 divider chain. The output of the latter is available at CLKOUT pin, and may be used for synchronization or to drive the clock input of a micro controller (the clock frequency value is around 848 kHz, resulting from division by 16 of reference frequency).

In FSK modulation mode, the subdivided clock is also FM-modulated (in accordance with the bit stream applied to FSKDTA modulator input) but the frequency shift is small and for most applications can be simply neglected. Assuming ± 64 kHz frequency shift for the generated RF signal, the relative “timing- jitter” as it appears at the CLKOUT pin has a peak-to-peak value of 3*10(exp-4) relative to reference signal duration by transmissions in the 433 MHz band and half of that value for transmissions in the 868 MHz band.

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If frequency modulation is used (FSK) Carson's bandwidth rule can be applied to define the approximate bandwidth requirements.

This rule is valid for communications system components using frequency modulated carriers modulated by signals which can be regarded as continuous in time domain and having a broader spectrum of frequencies (in frequency domain) rather than a single frequency component. The rule delivers accurate results for occupied bandwidth calculation if the modulating components are sine waves with a well defined upper frequency limit. However, there are certain limitations in bandwidth prediction accuracy if the modulating signal exhibits discontinuities (in time domain) such as a square wave or pulse (i.e. the equivalent Fourier series has a large number of components, or, theoretically speaking, an infinite number).
Nonetheless, due to the simplicity of Carson's bandwidth rule method, it is worthwhile using it for a first, even though coarse approximation of the occupied bandwidth estimate.

More elaborate methods, which take into account the discontinuities in the signal shape, deliver accurate results (i.e. the overtones are being considered, the signal is decomposed in Fourier series for analysis) but the background mathematical apparatus is a more complex one, and as for the computations, it usually requires a dedicated environment (software).

Carson's bandwidth rule is expressed by the relation

$$BWR = 2 \times (\Delta f + fm) \tag{3}$$

where *BWR* is the bandwidth requirement, *Δf* is the peak frequency deviation, and f_m is the highest frequency component in the modulating signal.

For example, an FM signal with 50 kHz peak deviation, and a maximum modulating frequency of 4kHz, would require an approximate bandwidth of 2*(50+4) = 108 kHz as predicted by above formula.
The maximum modulating frequency shall be computed according to the used encoding scheme.
For instance by NRZ encoding the fundamental frequency is half of the nominal datarate, by Manchester encoding it equals the datarate.

Note: theoretically speaking any frequency modulated signal, generated by an ideal modulator, and steered by a squarewave signal at input shall have an infinite number of sidebands and hence an infinite bandwidth but in practice all significant sideband energy (98% or more) is concentrated within the bandwidth defined by Carson's rule. This may be regarded as a useful approximation, but setting the threshold at 98% (of in-band power) by definition of occupied bandwidth still means that the power outside the band is only about 17 dB less than inside. Therefore Carson's Rule is of little use in spectrum planning, as the limit (maxima) of power falling into adjacent channel(s), allowed by most regulatory standards is well below -17 dBc.

2.3 Comparison of ASK versus FSK signal spectrum. A practical viewpoint.

As emphasized in the introductory part, quite often compatibility with already existing systems is one of the demands during the design of a new application. In this case practically all the main transmission parameters are set and fixed in advance and there is little room for change.
In contrary, by design of new applications a certain freedom in the transmission parameter choice is given, at least as long as the main criteria are:

- system cost
- reliability
- compliance with regulatory standards (usually region or country specific)

The system designer may face the question -Which is the best data rate choice and the suitable modulation type for the particular application?

As regarded form transmitter side, following aspects shell be taken in account:

- Transmission with low datarate yields narrower occupied bandwidth versus a high datarate transmission, for the same modulation mode. This saves a valuable resource - frequency band occupancy, and yields more margin by compliance with regulatory standards.
- Calculated for the same transmission capacity (expressed in bits/sec) transmission with lower datarate takes longer time, as with high datarate. Consequently, if the transmitter is operating with the same power (assumed not to depend on datarate) the total power consumption of the transmitter is higher for a low datarate system, as it shall stay active for longer time to achieve the same through output.
- If several transmitters, with overlapping coverage area are transmitting packets without a time-domain synchronization protocol (TDM) between the units (as they may belong to different networks or operate in stand-alone mode), the collision probability will increase by increase of transmission time of each individual transmitter (or to be more concise, by increasing duty cycle of the transmissions the collision probability will also increase).

If the transmission parameters are analyzed from the receive site’s viewpoint, the following aspects shall be considered

- As a low datarate transmission yields narrower occupied bandwidth (versus a high datarate one), the bandwidth of the intermediate frequency stage (IF) and post-detection filter (or data-filter, at demodulator output) may be reduced as well. Thus a reduction of the in-band noise power will be achieved, leading to better receiver sensitivity (versus a receiver with same gain and noise figure, but wider IF bandwidth).
- As already mentioned by the transmitter analysis, increased datarate would require a shorter active (receive) time for the same transmission capacity (expressed in bits/sec) versus a low-datarate system. Thus the power consumption of the receiver can be reduced by increasing the transmission speed, as the current consumption in active mode is usually much higher (by magnitudes) as the standby or sleep-mode current, drawn by receiver in idle mode.
- Receivers for frequency modulation (FSK) have a clear advantage over those built for amplitude modulation (ASK) in terms of noise immunity (and demodulator gain), as long as the RF or IF carrier to noise power ratio (C/N) does not drop below 6 dB. Below this threshold the peak detector of an AM system performs better (i.e. with better signal-to-noise ratio at the demodulator output) as the ratio detector or discriminator and even the PLL demodulator of an FM receiver.

Clearly, some of the above points are conflicting and a trade-off shell be met, therefore system designers are advised to set clear goals by project definition in terms of:

- Link budget (including required or targeted range, Tx power, Rx sensitivity and antenna gain of both sides)
- Energy budget (resulting from weighted sum of active and standby mode currents in the system)
- In case of battery operated applications the decrease of available voltage over the battery lifetime and an increase of the internal resistance, this latter limiting the maximum available current, which can be drained from battery before the minima of the system’s supply voltage is reached. It is worth to note that the battery voltage is also temperature dependent.

As regarding the choice weather ASK or FSK may suite better a particular application, it is worth to note that there are significant differences in the spectrum of the two carriers, one generated by AM modulator and the other by FM, even if the power of the unmodulated carrier would be the same.

In **Figure 6** the spectral plots of three signals are shown

- unmodulated carrier (CW) represented by the yellow plot
- the same carrier, but frequency modulated, with + 65 kHz frequency shift by an unshaped (square-wave) signal corresponding to Manchester encoded 9600 bit/sec data stream is plotted in light-blue
- again the same carrier, but amplitude modulated, with 100% modulation depth, by an unshaped (square-wave) signal corresponding to Manchester encoded 9600 bit/sec data stream is plotted in magenta

The plots have been recorded with the detector of the spectrum analyzer set to maximum hold mode (MaxHold) and a resolution bandwidth (RBW) wide enough not to show the individual spectral components, but sufficiently narrow to avoid significant distortion of the envelope's shape.

*Note: the fundamental frequency, equivalent with a Manchester-encoded signal of 9600 bit/sec is of 9.6 kHz. As the waveform is symmetrical (50% duty-cycle), sidetones with significant energy are expected at + (2n+1) * 9.6 kHz frequency offset, relative to the carrier.*

Measurements with the above listed instrument settings (trace MaxHold and 20 kHz RBW) yield envelope curves tangent to the peak values of the individual spectral components, in other words a worst case scenario, but close to the method the two widespread regulatory systems (ETSI EN 220-300 and FCC Part 15D) do use for measurement of out of band emissions.

Note: An instrument-grade RF generator have been used as signal source during the test, to keep distortions and intermodulation products at low level.

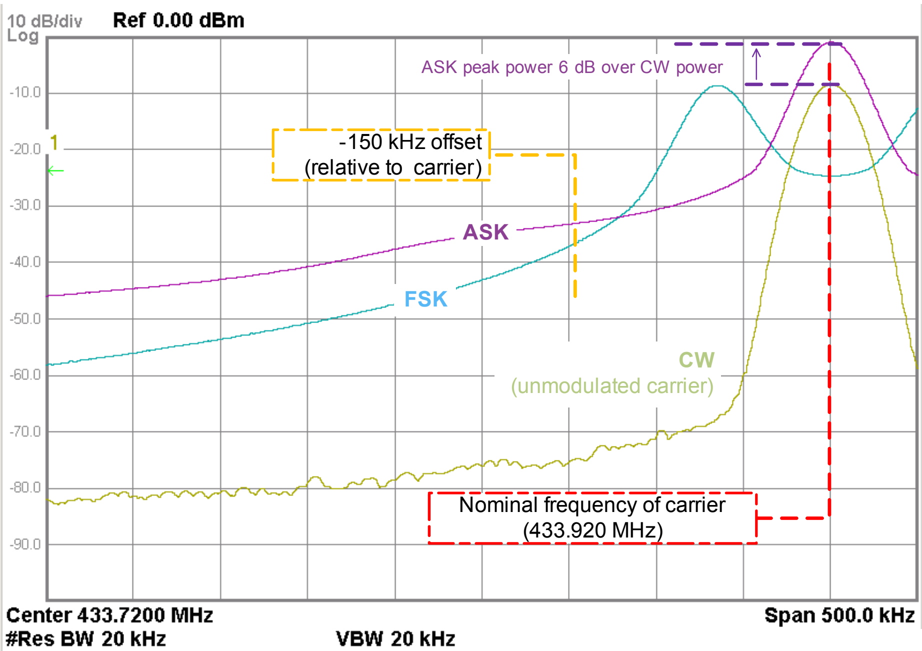


Figure 6 Occupied bandwidth of ASK and FSK signals for the same encoding scheme and equal datarate. Only the lower sideband is shown in this figure (as the two sidebands are expected to be symmetrical relative to carrier frequency).

Considering the results of above described test, following conclusions may be drawn:

- amplitude shift keying (ASK) concentrates significant amount of energy close to the carrier (i.e in the low order sidetones). The peak power of the ASK signal is exceeding by +6dB the power of the CW carrier.
- the amplitude of the high-order sidetones decreases by increasing frequency offset (relative to carrier), but the steepness of sidetone peak amplitude vs. frequency offset function is moderate above the 7th sidetone,

assuming the modulation depth is 100% or close to this value (i.e. if ON/ OFF keying is used). However, if the modulation depth is reduced to around 70..80%, the amplitude of high-order sidetones decreases faster (see **Figure 2** for relevant data) but the price for this enhancement is a certain increase in current consumption (mainly for the RF power amplifier).

- In conclusion ASK is at best suitable for low- or moderate speed transmissions.
  Power "leaking" into adjacent channels have to be considered, and if required, signal shaping applied.
- frequency shift keying (FSK) is characterized by two power peaks, placed under- and over the carrier frequency, at offsets equaling the positive and negative frequency shift values.
- if the modulation index is of a moderate value (3..5), by frequency offsets (relative to carrier) exceeding the double of the frequency shift value, the envelope, tangent to peak of the individual spectral lines decreases faster as by ASK modulation (for instance on left side of **Figure 6**, by frequency offsets exceeding 150 kHz). Assuming that the transmitter is modulated by a Manchester-encoded, 20 kbit/sec data stream and that the frequency shift, measured on RF carrier is 65 kHz yield a modulation index of 3,25 (65 / 20).
- In conclusion FSK modulation is more efficient, in terms of spectrum usage for medium and high datarates, but there are no other disadvantages (beyond a wider occupied bandwidth) to be used for low datarate transmissions as well.

Attention: at first glance the reduction of modulation index may appear as a straightforward way toward reduction of the occupied bandwidth. However, low modulation index values have an adverse effect on demodulator gain (in receiver), therefore users are advised to keep the value between 3 and 5.

*Note: assuming the crystal's parameters are known in advance, the amount of frequency shift, at reference frequency level can be set by proper choice of the values for load and frequency pulling capacitors (CV1 and CV2, see **Figure 10** and **Figure 11**.*
*As explained in **Chapter 2.2**, the frequency of the RF carrier is either 32 tor 64 times the reference frequency. Due to the inherent nature of the PLL, the frequency shift of the reference is also multiplied by 32 or 64 (as long as the bitrate of the modulation signal does not exceed the maxima specified in the specific TDA71xx/TDK51xx Datasheet).*
Consequently the effective frequency shift, referred to RF carrier is 32 or 64 times the shift of the reference frequency.

The results of occupied bandwidth measurement (OBW) are summarized below for the following test cases:

- two different bitrates, 2400 bit/sec, respectively 9600 bit/sec
- ASK and FSK modulation modes
- Manchester encoding (by all test cases)

*Note: for occupied bandwidth calculation the 99% in-band energy (of the total power) criteria have been used during the tests summarized in **Table 5**. As previously emphasized, different regulatory specifications may use other (usually more restrictive) maxima values for out of band and unwanted emissions.*
The compliance test shell be done as imposed by the specific regulation(s).

Table 5 Modulation Modes and Occupied Bandwidth summary

Datarate [bit/sec]	Modulation mode	Occupied bandwidth [kHz]	Note
2400[1)]	ASK	70	Modulation depth 100%
	FSK	140	Frequency shift ±40 kHz
9600[2)]	ASK	105	Modulation depth 100%
	FSK	210	Frequency shift ±65 kHz

1) Manchester encoded stream, 50% duty cycle symmetrical waveform, no shaping (low pass filter) on modulator input
2) Manchester encoded, 50% duty cycle symmetrical waveform, no shaping /power ramping

2.4 ASK/FSK modulator and power control in TDK51xx and TDA71xx

The bias circuitry is powered up via a voltage V > 1.5 V at the pin PDWN.

If the bias circuitry is powered up, the ASKDTA pin is pulled up internally.

Forcing the voltage at the pins low overrides the internally set state.

The block diagram of the modulator is shown in **Figure 7**.

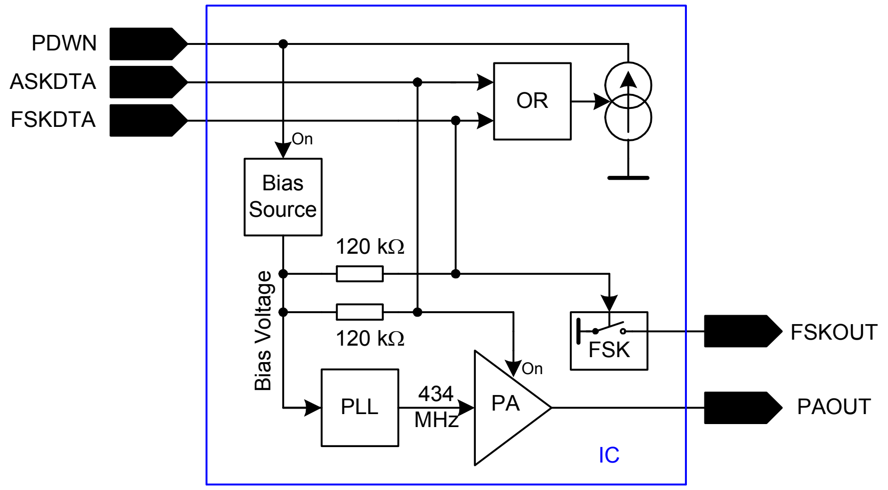


Figure 7 Block diagram TDK51xx;TDA71xx modulator and power control

Table 6 provides a listing of TDA7110F's powering states.

Table 6 Power Modes

PDWN	FSKDTA	ASKDTA	MODE
Low1)	Low, Open	Low, Open	POWER DOWN
Open2)	Low	Low	
High3)	Low, Open, High	Low	PLL ENABLE
Open	High	Low	
High	Low, Open, High	Open, High	TRANSMIT
Open	High	Open, High	
Open	Low, Open, High	High	

1) Low: Voltage at pin < 0.7 V (PDWN),
Voltage at pin < 0.5 V (ASKDTA; FSKDATA)

2) Open: Pin open

3) High: Voltage at pin > 1.5 V

Attention: Other combinations for the state of the control pins PDWN; FSKDATA; ASKDTA are not recommended

To avoid spurious radiation and spectral splatter it is strongly recommended to switch not directly from PDWN-mode to TRANSMIT-mode, but first to PLL-ENABLE-mode and start the transmission with a small delay, to make sure that

- the reference oscillator's startup time and
- PLL settling time (i.e. the time needed by PLL to "lock" on the reference oscillator's frequency)

elapsed, either like shown in **Figure 8** for ASK transmissions or, if FSK transmission mode shall be used, than according to a timing diagram similar to that shown in **Figure 9**.

Note: the oscillator startup time is expected in the 0.6..2msec range, the PLL lock time is typical below 0.1 msec

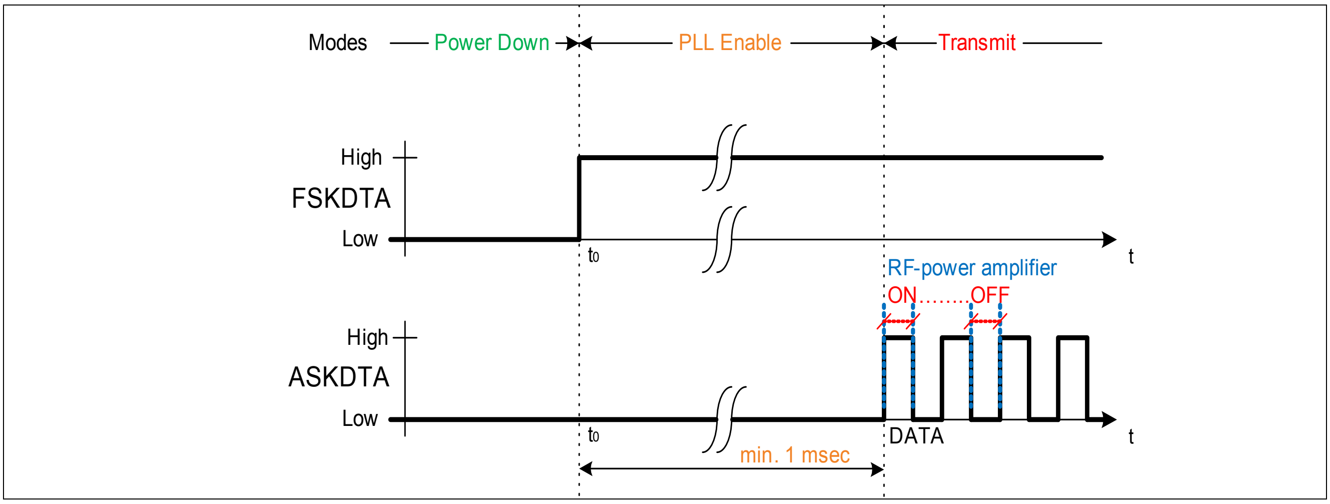


Figure 8 Timing of PLL activation and starting a transmission in ASK Mode

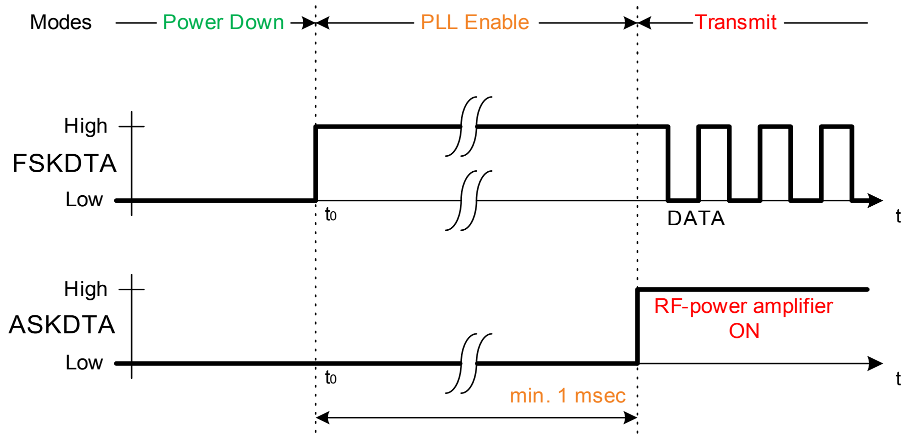


Figure 9 Timing of PLL activation and transmission in FSK Mode

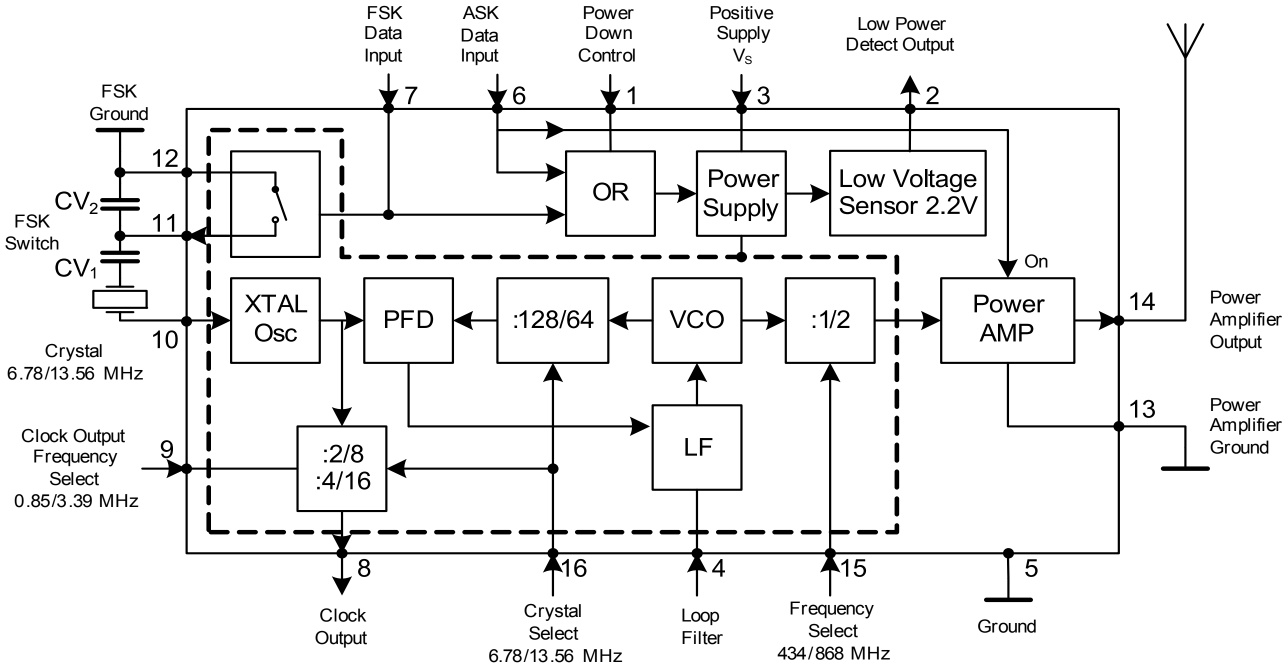


Figure 10 Block diagram of the TDK5110 transmitter (16 pin PG-TSSOP-16 green package)

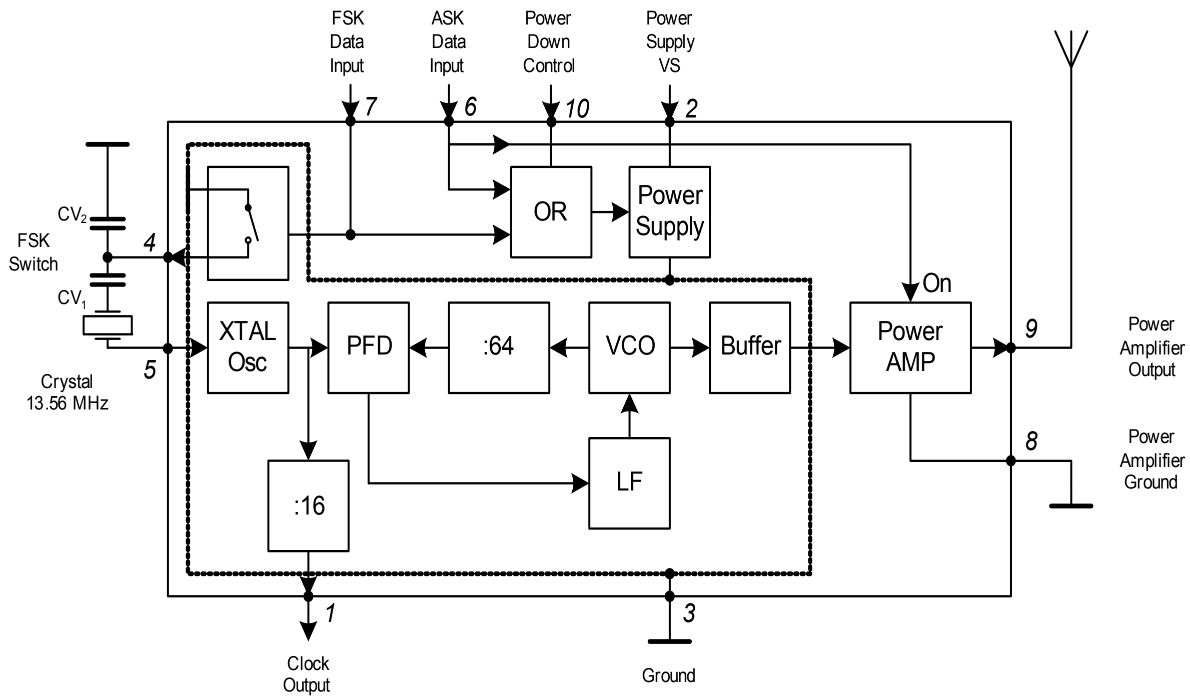


Figure 11 Block diagram of the TDA7116F transmitter (10 pin PG-TSSOP-10 green package)

3 Design hints and solutions

In subsequent parts of this chapter after a brief description of the hardware platform, the techniques of signal sloping and power ramping will be examined, based on a Keyfob Demonstrator as design example.

The Keyfob is built around a TDA7116F transmitter and a third party, low-voltage microcontroller chip.

3.1 Hardware

The schematic diagram of the Keyfob Demonstrator is shown in **Figure 12**. The unit operates in the 868 MHz band and the modulation mode may be configured either for ASK or for FSK per conditional directives during Firmware compilation.

Note: implementation of mixed mode modulation schemes based on this project are also possible (for instance synchronization bits transmitted with ASK modulation, followed by payload transmitted with FSK mode).

For reference frequency generation a crystal of nominal frequency equal with 1/64 of the desired transmit frequency is required. The chip-internal synthesizer in TDA7116F transmitter is of integer-N type, this meaning that the VCO's output frequency in stationary mode (i.e after the VCO pulls in and the PLL achieves phase-lock) is an integer multiple (*64*) of the reference frequency (f_{ref}), which is derived from the crystal oscillator.

$$f_{carrier} = 64 \times f_{ref} \tag{4}$$

To ensure maximum flexibility in system design and during evaluation work, the Keyfob Demonstrator has been designed to be configured for:

- ASK modulation scheme or
- FSK modulation scheme

by choice of appropriate Firmware version, containing conditional directives (for ASK and FSK functionality) embedded in the source code.

The antenna type is configured during board assembly, either for:

- electrical antenna (monopole) or for
- magnetic loop antenna

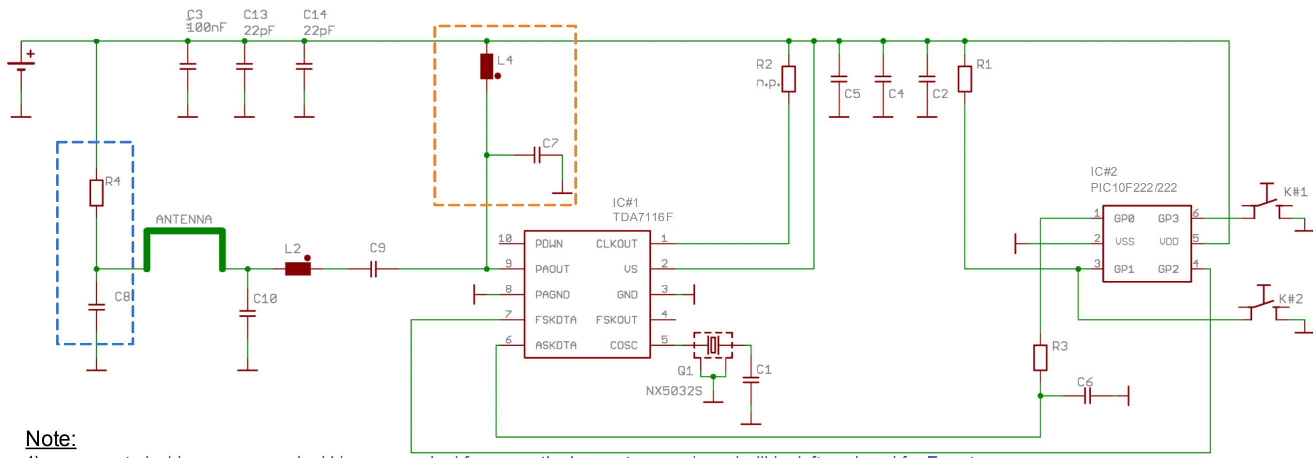
If the coil *L4* is placed but the components annotated as *R4* and *C8 are* left unplaced, the resulting radiator will be a monopole (E-field antenna).

Provided a magnetic loop antenna setup, the RF-current component will flow through the entire antenna structure. By this setup *L4* will be left unplaced and the RF power amplifier will be fed with supply voltage over the current limiting resistor *R4*.

If the capacitor C8 is of low value or unplaced (resulting a high reactance value), R4 will introduce some degree for damping in the antenna circuit, a useful feature for suppression of parasitic resonances.

On the other hand, if *C8* has a high value (of around 22 pF or above) then the common node of *R4; C8* and the loop antenna are practically grounded, and *R4* acts like a current limiting resistor for the DC component flowing through the collector of the RF power amplifier transistor.

As such the current consumption of the RF end-stage can be reduced, and the amount of RF power delivered by the power amplifier shall decrease simultaneously.
This way of RF power reduction may be an option for short-range, low power radio links.



Note:
1) components inside squares marked blue are required for magnetic loop antenna only and will be left unplaced for E -antenna
2) components inside squares marked with orange are required for E -antenna only and will be left unplaced for loop antenna

Figure 12 TDA7116F Keyfob Demonstrator schematics, configured for ASK modulation scheme. Unplaced components are hidden. Placed 0R bridges shown as continuos wire segments for ease of signal tracking in this drawing.

The microcontroller embedded in the keyfob unit scans the key matrix (seeking also for states like multiple, simultaneously depressed keys). Based on a unique representation of the code associated to depressed key(s), it encodes the data (possibly applying also a scrambling or encryption algorithm). The encoded data becomes part of the payload. Depending on the requested ruggedness of the link, in addition to the data, error detection or detection and correction information may be embedded into the payload part.

Based on the frame content to be transmitted, the microcontroller assembles the frame (which apart from the previously mentioned payload may also contain other fields, meant for signaling and synchronization), applying the frame bit by bit (or chip by chip) to the modulator input(s).

At the same time the microcontroller generates the control signal(s) for the TDA7116F radio transmitter.

The power management is also part of the microcontroller's tasks, the device putting itself and the TDA7116F in sleep mode (power down) after transmission of the frame, provided the scan does not identify any other depressed key. The microcontroller will commence code execution by the entry point following the SLEEP instruction on subsequent key activation, assuming that before entering the sleep mode the "*wakeup on pin state change*" function were activated.

As part of the power management, the supply voltage level is monitored. This is accomplished by sampling the supply voltage value over the microcontroller's internal A/D converter (at best before starting an RF-transmission).

In order to prevent transmissions on erroneous frequencies, systematic check of supply voltage value is an appropriate method (and associated with high confidence level) if performed before or during the transmission of frame.

Attention: *Operating the RF transmitter below the* ***minima*** *of allowed supply voltage (of 2.1 V according to TDA7116F Datasheet) may result in PLL unlock. This may yield frequency error of the transmitted signal beyond the regulatory (legal) limits.The reason for this is that even if the phase detector, the VCO and the RF power amplifier are still working by "forced" operation below supply voltage minima, the tuning range of the VCO may slide out of the nominal range, thus frequency error may occur.*

Attention: *Operating the RF transmitter beyond the* ***maxima*** *of allowed supply voltage (of 4 V according to TDA7116F Datasheet) may result in irrecoverable damage to the chip.*

During idle time (i.e. no key is depressed and there is no ongoing transmission) the microcontroller switches the transmitter in power down mode by pulling low, the following lines

- PDWN (Pin 10; TDA7116F)
- ASKDTA (Pin 6; TDA7116F)
- FSKDTA (Pin 7; TDA7116F)

followed by execution of a SLEEP instruction, thus placing itself also in low power mode.

Note: instead of controlling all the 3 lines (PDWN; ASKDTA; FSKDTA) the power down line (PDWN) may be left floating and both ASKDTA and FSKDTA pulled low to enter power down mode (as shown in ***Figure 12****).*

Once the sleep mode is entered, the current consumption of the full system is maintained at very low level.
If a key is depressed (U$3 or U$4 in schematics **Figure 12**) the microcontroller is awaken from sleep mode and code execution commences.

The antenna feedpoint impedance and that of the chip internal RF power amplifier in the TDA7116F are matched, by the impedance matching network comprising the following elements

- *C9; L2; C10; C8* and *R4* if a loop antenna configuration is used (*L2* and *C7* are unplaced in this case)
- *C7; L4; C9; L2;* and *C10* if a monopole antenna configuration is used (*C8* and *R4* are unplaced in this case)

It is common sense that the component values in those impedance matching networks are determined by

- output impedance of the RF power amplifier and
- the radiation impedance of the antenna.

The latter is strongly influenced by antenna type (monopole or magnetic loop) even if the physical length of the conductive structures (striplines) is the same for both antenna versions (same PCB layout).

The two antenna types may have very different radiation impedances, even if the operating frequency is the same.

The main goal of the antenna optimization in a Keyfob is:

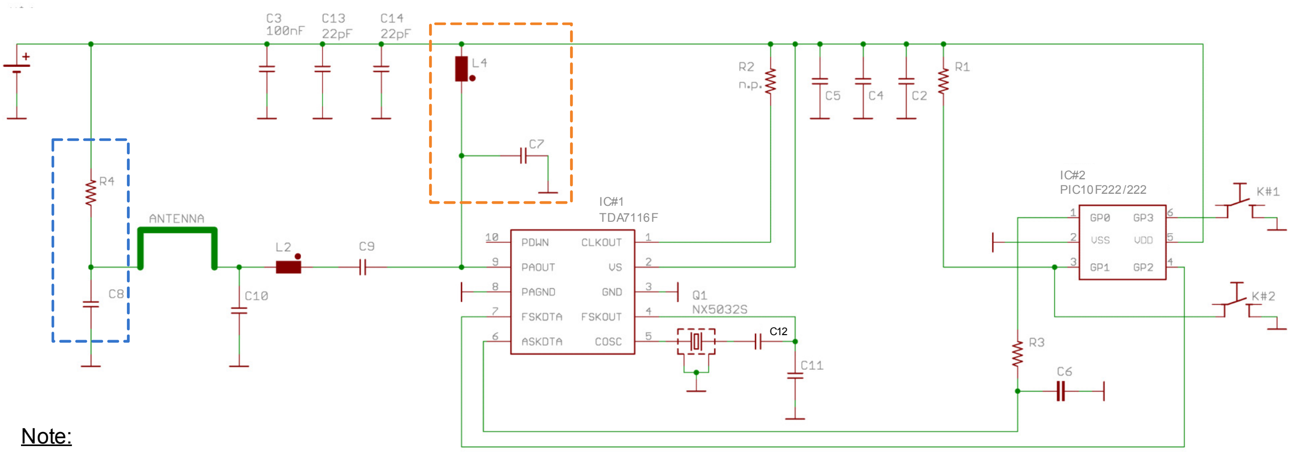
- achievement of a reasonable antenna gain under variable (and not always easily predictable) environment impedance conditions (due to close-field coupling).
- at the same time the ideal radiation pattern of a Keyfob would be an omnidirectional one. Close field coupling effects have to be considered if the Keyfob is held in hand, as human tissue may cause RF energy absorption and capacitive coupling

Meanwhile radiation impedance of antennas is frequency dependent.

The main goal of the matching network optimization is:

- achievement of simultaneous match at both ports (RF power amplifier and antenna) or at least keeping the reflection losses below a reasonable level
- minimization of insertion loss (as this causes power loss)

For all the above reasons the component values in the impedance matching network turn out to be antenna type and frequency band dependent.



Note:
1) components inside squares marked blue are required for magnetic loop antenna only and will be left unplaced for E -antenna
2) components inside squares marked with orange are required for E -antenna only and will be left unplaced for loop antenna

Figure 13 TDA7116F Keyfob Demonstrator schematics, configured for FSK modulation. Unplaced components are hidden. Placed 0R bridges shown as continuos wire segments for ease of signal tracking in this drawing.

3.2 Proper PLL timing, signal shaping and power ramping techniques

In order to minimize the spectral splatter and perturbation of adjacent channels it is recommended to proceed before and during transmissions as per the sequence described below:

- at the beginning of a transmission (e.g. frame) the PLL is activated for around 1..3 msec, yet without activating the RF power amplifier
  This time is sufficient for the reliable startup of the crystal oscillator. Actually the crystal begins to swing much earlier, but according to definition, startup time equals the time elapsed from powering the oscillator until to the oscillation amplitude shall have reached 90% of the stationary value.
  In order to operate properly, the phase comparator (which is part of the on-chip synthesizer), requires a certain level of signal at both inputs (i.e. inputs from reference oscillator and the integer-N divider). Levels below limit are usually associated with erroneous comparator output or at least with a noticeable increase of the jitter at the output. This jitter cannot be eliminated entirely by the loop filter, and it may thus degrade the phase noise figure of the transmitter (at least for the time the signal levels are low and the jitter high).
  Transmitters of the TDA71xx/TDK51xx family are designed to operate (under normal conditions) with low phase noise and jitter. After the startup time has been elapsed the drive level required for proper operation of the phase comparator shall be duly reached, and the issue mentioned in the above paragraph shall only apply to the transient mode of the oscillator. Thus if the RF power amplifier is activated too early, or if the reference oscillator is driven by an external signal with insufficient level (for instance a TCXO, with too low drive level) frequency error may occur or degradation of the output signal's phase noise ratio may result.
  The oscillator startup is followed by the active transmission phase. At this stage there are differences between ASK and FSK operation mode, details being explained below:

  – For transmissions using **ASK** modulation scheme (whereas the transmitter schematics matches the simplified version as shown in **Figure 12**), the **FSKDTA** line shall be held high (to keep the PLL in active state) while the **ASKDTA** pin is pulsed according to the data stream and the implemented encoding scheme. Thus the RF power amplifier is switched ON and OFF, as shown in **Figure 8**. Meanwhile the reference oscillator and synthesizer part - VCO included - will remain all the time ON during the ongoing transmission and switched OFF at the end of transmission.
    In other words the amplitude shift keying (ASK) is accomplished at the RF power amplifier level.[1)]

– If **FSK** modulation scheme is used (whereas the transmitter schematics matches the simplified version as shown in **Figure 13**,) the timing diagram shall be similar to that shown in **Figure 9**.
  During oscillator startup and PLL acquisition time the **FSKDTA** line shall be held high (to set and keep the PLL in active state) and **ASKDTA** shall be pulled low, thus holding the RF power amplifier in inactive state thus avoiding transmission with unlocked PLL.
  This phase is shown by the mid-portion (of time axis) in **Figure 9**, marked with PLL-Enable.
  After the startup time have been elapsed the active transmission part follows, realized by pulsing the **FSKDTA** pin in accordance with the data stream and the used encoding scheme, while keeping the **ASKDTA** pin high, thus enabling the RF power amplifier.
  As a consequence an RF carrier with practically constant envelope but variable frequency will be output by the RF power amplifier.

Both timing procedures as listed above (associated with **ASK** and **FSK** modulation) will render a margin that shall be suffice for the reference oscillator to start up and it will just as well grant the PLL the necessary time to pull in (on reference frequency) and achieve phase-lock.

Note: The startup time of the Reference Oscillator is imposed mainly by

1. *the gain of the NIC type oscillator itself (negative resistance **-R** of the **N**egative **I**mpedance **C**onverter) and*
2. *the equivalent R; L; C parameters of the used crystal, major influence being derived from equivalent* R_s *of the crystal (see the **TDA7116F Datasheet** for computation of Startup Time and Oscillator Margin)*

If the Keyfob is intended solely for ASK modulation, a single load capacitor, *C1*, connected in series with the crystal shell be required, as shown in **Figure 12**. The value of this capacitor shall be in accordance with the load capacitor range, as indicated in the datasheet of the particular crystal by its manufacturer.

Fine tuning of the channel frequency is possible by means of changing the value of *C1* as long as this variation complies with the range of load capacitance, specified in the datasheet of the crystal. For fine tuning purposes two capacitors may be connected in series.

This would yield much finer tuning steps as for instance a single component of the E24 range would permit.

3.2.1 Signal shaping

A simple, yet efficient measure aiming minimization of spectral splatter consists of steering the AM modulator (in fact the RF-power amplifier block) using a ramped signal with moderate slew-rate on both, the leading and the trailing edge instead of a fast-rising digital signal (i.e. with high slew-rate).

The group *R3* and *C6* (schematics **Figure 12**) is implementing this function, acting as a low-pass filter with moderate cut-off frequency. The RF transients generated by moderately “rounded” modulation signals, generate RF carrier pulses with shaped envelope, alike the ones shown in the mid and right side of **Figure 4**. Such pulses contain less high order harmonics energy, thus causing less perturbation in the adjacent channels and less spectral splatter as the high slew-rate signal, shown on the left-hand side of the same figure.

It is recommended to choose a time-constant for the mentioned RC group of around 1/6 of the bit duration if NRZ modulation is employed or 1/6..1/10 part of the bit duration if a DC-free encoding scheme is used (for example Manchester).

Detailed explanation regarding the benefits of the procedure (i.e. signal shaping) are provided in **Chapter 2 Modulation parameters and their influence on signal spectrum**.

1) As the VCO is always ON during active transmission, there may be a minor level of RF energy leaking from VCO toward the output of the RF power amplifier, even if this amplifier is OFF. The level of leakage is well below the admitted regulatory threshold (usually by around -70 dBm, measured at RF PA pin) and depends at large extent from the quality of the (external) decoupling capacitors.

This simple method of shaping with a lowpass filter is suitable for low and medium datarates.

Assuming that the bitstream applied to modulator is Manchester encoded, the mentioned solution may enhance the spectral distribution of the sidetones (and reduce the high-order ones at some extent) for transmission speeds up to 2 kbit/sec. By 4 kbit/sec it is still usable, depending on how strong the edges of the square-wave signal are beveled.

A further enhancement may be achieved by a lowpass or bandpass filter with DC-free coupling and self-centering (basically a DC-blocking capacitor between the integrator capacitor and the ASK input pin of TDA71xx/TDK51xx).

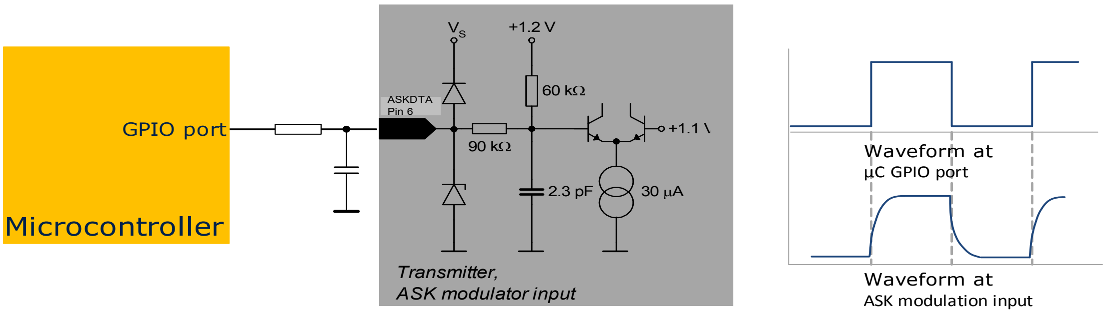


Figure 14 Waveform shaping with lowpass filter

3.2.2 Power ramping

As emphasized in **Chapter 2 Modulation parameters and their influence on signal spectrum**, the suitability of ASK modulation scheme for transmissions compliant with ETSI EN 300-220 standard by medium and high datarates is limited mainly by the fact that high-order harmonics of the modulations signal (overtones), represented by discrete lines in the spectrum may "stick" through the spectrum mask if

- the RF power is switched on and off by a digital signal, with short rise and fall time. The root cause is the high harmonic content of a square-wave pulse. Further, if there is no bandwidth limiting (lowpass) filter in the ASK modulator pass, the envelope of the generated RF pulse shall be also steep, and the transient may cause noticeable spectral splatter. This may become an issue for regulatory compliance, especially if the radiated RF power (corresponding to CW carrier) is not set for very low level.

As the mentioned ISM band transmitter chips (TDA71xx/TDK51xx) use C-class RF power amplifiers for efficiency reasons, and such amplifiers are inherently non-linear in terms of output power versus input power characteristics, there are no simple means for control of the output power over the control of the RF driver signal level.

A more efficient way for RF power control by C-class amplifier is to:

- keep the RF driver signal level applied to the C-class amplifier's input quasi constant (however there is no need for accurate level control) and
- control the RF output power delivered by the amplifier by control of the supply voltage level.

By an ideal, non saturating amplifier the output power is proportional with the square of supply voltage (if assuming a constant load).
The main drawback of the simple shaping filter analyzed in previous **Chapter 3.2**) is that:

- the output power of the RF power amplifier is controlled not in a straight manner (over supply voltage level), but an indirect one, by means of controlling the driver signal level
- close to it's nominal maximum output power the C-class amplifier is pushed already in deep compression (which is benefic for efficiency) but the resulting RF input power versus output power transfer function is strongly nonlinear.
  Therefore it is not a simple task for systems lacking a Cartesian feedback path to achieve the degree of linearity required for the shaping function, even if the linearity required is, in absolute terms much lower as by systems using QAM or pure AM instead of ASK modulation scheme)

Note: systems using Cartesian feedback derive a part of the output RF signal, usually over a directional coupler and a feedback path to an error amplifier. The level of driver signal applied to the RF power amplifier 's input is controlled by the mentioned error amplifier. By this means the inherently nonlinear RF power amplifier can be linearized, but at the cost of increased system complexity and cost.

In order to control directly the output power of an RF power amplifier other solutions have to be considered, for instance those with direct control of the stage's supply voltage.

For a real (saturating) amplifier the RF power versus supply voltage curve is similar to that drafted on the right side of **Figure 15**. Despite nonlinearity, this transfer function is good enough to implement based on it an RF power ramping function.

Instead of abruptly switching on the RF power amplifier (which would reach, after a short transient the maximum power state in short time)

- the supply voltage of the power amplifier is raised gradually, until the output power reaches its maxima, but
- the driving RF signal is applied from the very first moment of the activation, practically at constant level

In this simple way RF pulses with moderate rise end fall time of the envelope can be generated, which are expected to cause significantly less spectral splatter as pulses with steep rising edge of the envelope.

Note: the transient corresponding to off-on transition of the RF power amplifier is more critical from spectral splatter viewpoint and the main cause for out of band perturbations, the on-off transient is less critical

In **Figure 15** a solution for RF power ramping, using a few external components is shown. The digital pulses of the bit stream to be transmitted (encoded according to used encoding and perhaps encryption scheme) are applied at the same time

- to the ASK modulation input of the transmitter and
- to the R8 and C7 integrator group

The voltage from the integrator is then applied to the tracking amplifier (consisting of T2; T3 and some passives). The output of the tracking amplifier is at the same time the supply voltage node of the RF power amplifier.

The square wave pulses, output by the microcontroller are integrated and at the output of the tracking amplifier appear as pulses with moderate slew rate (as shown on the right side of **Figure 15**). As he RF power amplifier is fed (supplied) with a variable voltage, the output RF power will exhibit the effect of supply voltage variation. Thus the envelope of the RF pulses has also a moderate slew rate.

The energy, contained in the pulse is concentrated close to the carrier frequency, and the amplitude of the high-order overtones decays significantly faster as it would happen by a square-wave RF envelope.

Thus spectral splatter (due to fast transients) and occupied bandwidth are reduced at the same time.

Note: by this circuit the supply voltage of the RF power amplifier decays slowly after the falling edge of the digital pulse (output by the microcontroller). As the same pulse is applied to the transmitter, and during LOW state of ASKDTA input the RF PA is switched off (by transmitter-internal logic) the slowly decaying supply voltage (of RF power amplifier) is not an issue.

Beyond slight increase of eBOM (due to external components) the only drawback of the solution is a small decrease of available supply voltage, due to the V_{CE} saturation voltage of *T3*. Assuming that the current drained by RF power amplifier is in range of 10..14 mA (typical value for +10dBm output power at 2,2V supply voltage) the V_{CE} saturation voltage of *T3* is expected in range of 60..120 mV (depending on transistor type and tracking amplifier gain).

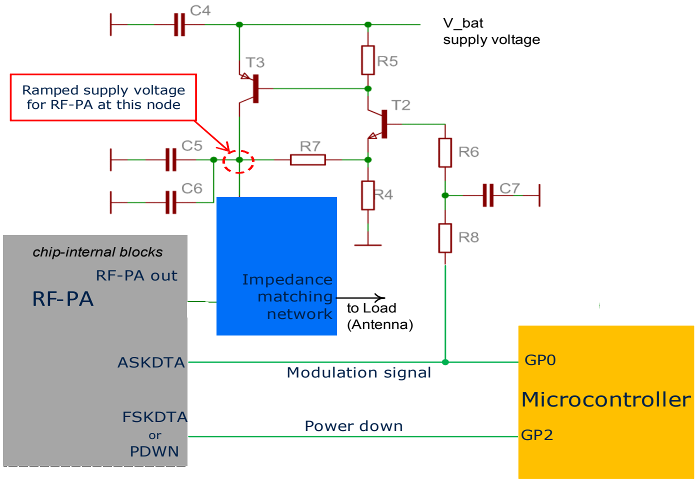


Figure 15 Ramping the supply voltage for RF power amplifier with an integrator and tracking amplifier

The solution works well up to the maximum datarate specified for the TDA71xx/TDK51xx transmitter family of 20 kbit.

A simplified version for RF power ramping is shown in **Figure 16**.

The solution assumes:

- either the usage of an inverter (if the RF power ramping is steered by the same GPIO port of the microcontroller which is used for data bitstreem output) or
- two separated GPIO lines are used (the state of the second is the inverted copy of the first)

Instead of a bipolar transistor a small P-channel MOSFET may be used as well. In this case, versions with low R_{DS_ON} value are preferred in order to minimize the voltage drop across the transistor.

Resistor *R1* may be left unplaced and the RF power amplifier supplied only over transistor *T1*.

If R1 is placed, it feeds the RF power amplifier with low voltage. By turning *T1* on, it will bypass the *R1* resistor and rise the supply voltage.

It is worth to note that the power ramping is achieved by gradually increasing the V_{BE} or V_{GS} voltage of the transistor (over the *C4; R2*||*R3* integrator group) instead of turning it abruptly on and off.

Set *R1* resistor value so to reach around 1/4 of the final (stationary) supply voltage level with *T1* off, and the further rise of supply voltage shall be “contributed” by *T1*, which bypasses R1, if steered into conductive state.

The solution have been tested with TDA7116F and performed quite well (with sufficient margin regarding the EN 300-220 mask limits) for Manchester encoded ASK transmissions up to 4,8 kbit/sec speed.

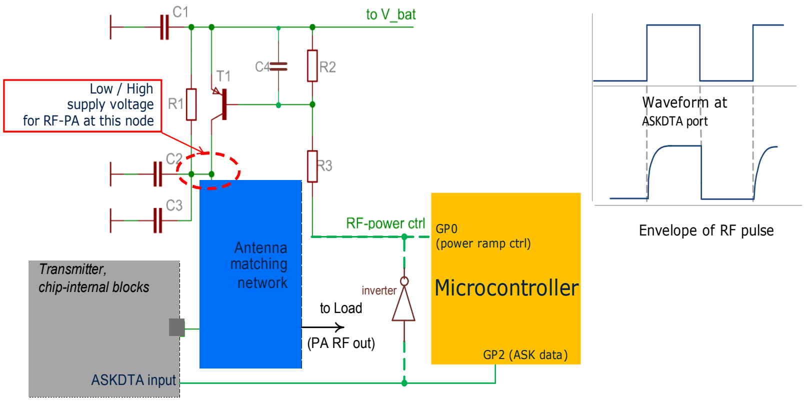


Figure 16 Simplified version for power ramping

References

[1] Infineon Technologies AG *General application note on electromagnetic radiation* **weblink**

[2] Infineon Technologies AG *Stabilizing the RF power of transmitters operating in ISM bands* **weblink**

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[4] Infineon Technologies AG *TDK5110 Datasheet* **weblink**

[5] Infineon Technologies AG *TDA7116F Datasheet* **weblink**

[6] Infineon Technologies AG *TDK116F Datasheet* **weblink**

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