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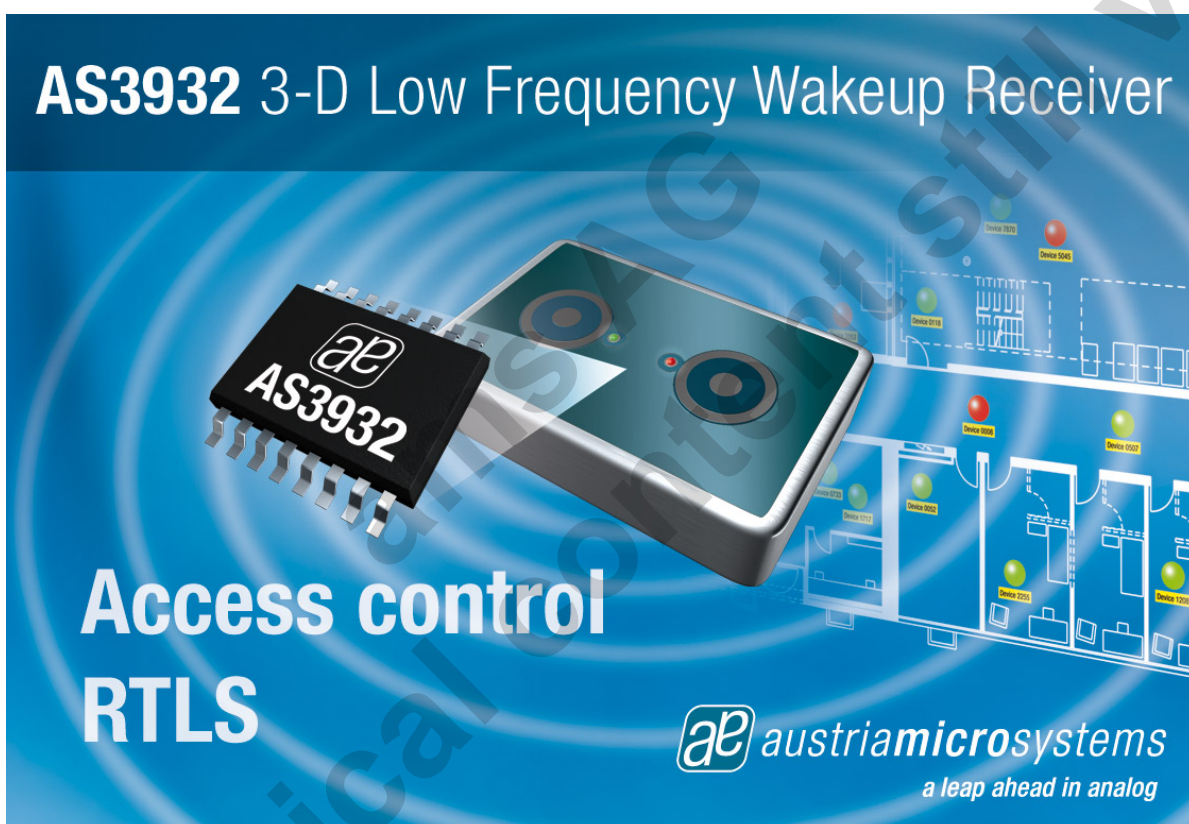
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## Application Note

# AS3932 Tank Circuit Design



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## Revision History

Revision	Date	Description
1.0	August 20, 2009	Initial version
1.1	October 8, 2009	New title page Correction of bandwidth calculation in equation 6 on page 9 and 7 on page 10 Correction of all related examples

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# Contents

<b>1</b>	<b>General</b>	<b>4</b>
<b>2</b>	<b>Basics about Tank Circuits</b>	<b>5</b>
2.1	Choosing a tank circuit design . . . . .	5
2.1.1	Receiver . . . . .	5
2.1.2	Transmitter . . . . .	5
2.2	Parallel Tank Circuit . . . . .	5
2.2.1	Resonance Frequency . . . . .	6
2.2.2	Q Factor . . . . .	6
2.3	Series Tank Circuit . . . . .	7
2.3.1	Resonance Frequency . . . . .	8
2.3.2	Q Factor . . . . .	8
<b>3</b>	<b>Basics about ASK and OOK</b>	<b>8</b>
3.1	Bandwith of an OOK signal . . . . .	9
3.1.1	NRZ coding scheme . . . . .	9
3.1.2	Manchester coding scheme . . . . .	9
3.2	Q Factor and signal bandwidth . . . . .	10
3.2.1	Major disturber in Germany . . . . .	11
<b>4</b>	<b>Basics for Coil design</b>	<b>12</b>
4.1	Induced voltage . . . . .	13
4.1.1	Air coil . . . . .	13
4.1.2	Ferromagnetic Core . . . . .	14
4.2	Inductance of the coil . . . . .	14
4.2.1	Air coil . . . . .	15
4.2.2	Ferromagnetic core . . . . .	15
4.3	Parasitics . . . . .	15
<b>5</b>	<b>Tank circuit design</b>	<b>16</b>
<b>6</b>	<b>Copyrights</b>	<b>18</b>
<b>7</b>	<b>Disclaimer</b>	<b>18</b>
<b>8</b>	<b>Contact Information</b>	<b>18</b>

## List of Figures

1	Parallel Tank Circuit . . . . .	5
2	Bandwith for a parallel circuit . . . . .	6
3	Series Tank Circuit . . . . .	7

4	Spectrum of an OOK signal . . . . .	9
5	Example of a NRZ signal . . . . .	9
6	Example of a Manchester coded signal . . . . .	10
7	Real coil . . . . .	16

## 1 General

The AS3932 is a 3-channel low power ASK receiver that is able to generate a wakeup upon detection of a data signal which uses a LF carrier frequency between 110-150 kHz. The integrated correlator can be used for detection of a programmable 16-bit wakeup pattern. The device can operate using one, two or three active channels.

Some of the key features are

- 3-channel ASK wakeup receiver
- Carrier frequency range 110 - 150 kHz
- One, two or three channel operation
- Reliable 1-, 2- or 3-D wakeup pattern detection
- Programmable wakeup pattern (16bits)
- Manchester decoding with clock recovery
- Digital RSSI values available for each channel
- Integrated RTC based on 32kHz XTAL or RC-OSC
- Bidirectional serial digital interface (SDI)

The programmable features of the AS3932 enable to optimize its settings for achieving a longer distance while retaining a reliable wakeup generation. The sensitivity level of AS3932 can be adjusted in presence of a strong field or in noisy environments.

The AS3932 is ideal for

- Active RFID tags,
- Real-time location systems,
- Operator identification,
- Access control and
- Wireless sensors.

The performance of the system depends mainly from the design of the used tank circuits. How it can be done and which requirements are to be met is the goal of this application note. It will help answering several questions when designing this tank circuits.

## 2 Basics about Tank Circuits

The name *Tank Circuit* is another name for a RLC circuit used in different electronic systems. There are, as one knows, two different circuits possible:

- A parallel tank circuit as shown in figure 1 and
- a series tank circuit as shown in figure 3 on page 7.

The main difference between both circuits is the impedance at the resonance frequency. A parallel tank circuit has the maximum impedance at the resonance frequency, a series tank circuit the minimum impedance at the resonance frequency, defined by the resistor  $R$ . This keep in mind when choosing a circuit for the receiver or the transmitter. The next section will give some hints for this.

### 2.1 Choosing a tank circuit design

What is the best tank circuit design for a systems? This depends on the impedance of the connection pins of the application.

#### 2.1.1 Receiver

Normally a receiver has a high impedance at the input. For an impedance matching the impedance of the tank circuit should also be high. As described before, only the parallel tank circuit has a high impedance at resonance frequency and is therefore the right choice for the receiver.

#### 2.1.2 Transmitter

A transmitter has always a low impedance at the output. For a correct impedance matching the tank circuit in this case has to have a *low* impedance. Now one can see, that a series tank circuit is much better than a parallel tank circuit.

### 2.2 Parallel Tank Circuit

First start with the parameter calculations for a parallel tank circuit as shown in figure 1.

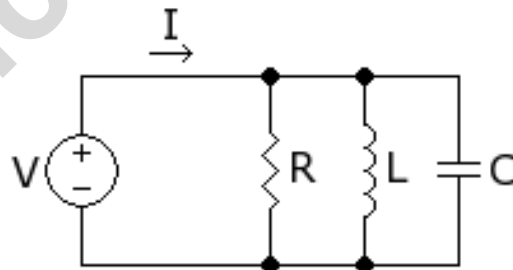


Figure 1: Parallel Tank Circuit

### 2.2.1 Resonance Frequency

The resonance frequency  $f$  is given by

$$f = \frac{1}{2\pi\sqrt{LC}} \quad (1)$$

### 2.2.2 Q Factor

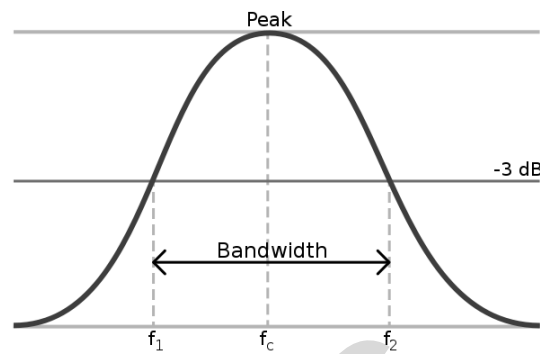


Figure 2: Bandwidth for a parallel circuit

The Q factor is given as shown in figure 2 by

$$Q = \frac{f_c}{f_1 - f_2} \quad (2)$$

The difference  $f_1 - f_2$  can be defined as the bandwidth  $B$ . Now the equation 2 can be written as

$$Q = \frac{f_c}{B} \quad (3)$$

The Q factor can also be calculated from the given devices. For a parallel circuit it's given by

$$Q = R\sqrt{\frac{C}{L}} \quad (4)$$

It's easy to see that a high value of the resistor  $R$  results in a high Q factor. It can also be seen, that the inductance and the capacitor has an influence to the Q factor. It is later shown that you can run in an optimization problem at this point, if the values of the inductance and the capacitor is not well chosen.



**Example 2.1**

The center frequency  $f_c$  is given with 125 kHz and there is a bandwidth  $B$  required with 15 kHz. Then the Q factor is given with equation 3 on the previous page by

$$Q = \frac{125\text{kHz}}{15\text{kHz}} = \underline{\underline{8\frac{1}{3}}}$$

**Example 2.2**

The values for a parallel tank circuit are given by

- $f = 125\text{ kHz}$
- $R = 2\text{ M}\Omega$
- $L = 7\text{ mH}$
- $C = 230\text{ pF}$

With equation 4 on the preceding page the Q factor is calculated as

$$Q = 2\text{ M}\Omega \sqrt{\frac{230\text{ pF}}{7\text{ mH}}} \approx \underline{\underline{362}}$$

**2.3 Series Tank Circuit**

Figure 3 shows a series tank circuit.

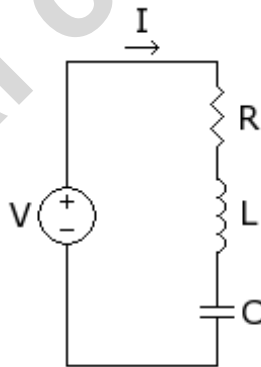


Figure 3: Series Tank Circuit

### 2.3.1 Resonance Frequency

For a series tank circuit the resonance frequency is calculated in the same way as for a parallel circuit, described in section 2.2.1 on page 6.

### 2.3.2 Q Factor

The Q factor is given by

$$Q = \frac{1}{R} \sqrt{\frac{L}{C}} \quad (5)$$

If a high Q factor is required, a small resistor  $R$  has to be chosen. The resistor  $R$  can be the parasitic resistor of the coil.

#### Example 2.3

The values for the series tank circuit are given by

- $f = 125 \text{ kHz}$
- $R = 10 \ \Omega$
- $L = 7 \text{ mH}$
- $C = 230 \text{ pF}$

With equation 5 the Q factor is calculated as

$$Q = \frac{1}{10 \ \Omega} \sqrt{\frac{7 \text{ mH}}{230 \text{ pF}}} \approx \underline{\underline{18}}$$

## 3 Basics about ASK and OOK

The ASK (Amplitude Shift Keying) modulation is a special form of a normal AM (Amplitude Modulation). It's mainly used to transmit digital data. For every bit, which will be transmitted, a special amplitude is defined.

#### Example 3.1

The European clock reference is sent via the DCF-77 transmitter [2], which uses three different power levels for the data:

- 100% with no special informations,
- 25% for data, encoded in the length of the decreased amplitude, and
- 85% for special data.

A very simple form of an ASK modulation is the OOK (On-Off-Keying) modulation. When using OOK, only the carrier will be switched on and off.

### 3.1 Bandwith of an OOK signal

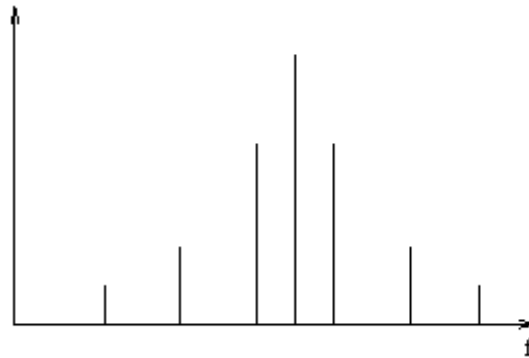


Figure 4: Spectrum of an OOK signal

Figure 4 shows the spectrum of an OOK signal. It can be shown, that the harmonics of the data signal can be disregarded.

The AS3932 provides the possibility of the demodulation of a simple bit stream (for example a NRZ signal) or of a Manchester coded signal. To determine the minimum required bandwidth, one has to look first at the coding scheme of the used data stream.

#### 3.1.1 NRZ coding scheme

If the data stream is a NRZ coded signal (see [7] for more details), the bandwidth is given by

$$B = \text{data rate} \quad (6)$$

Figure 5 shows an example of a NRZ signal.

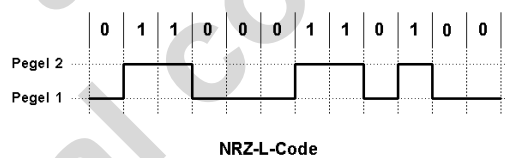


Figure 5: Example of a NRZ signal

A NRZ signal needs always synchronization pulses or synchronisation data inside the data stream.

#### 3.1.2 Manchester coding scheme

If the data stream is Manchester coded, than the required bandwidth is two times of a NRZ coded signal. This has the reason in the special way, a Manchester signal looks like. Inside the Manchester coded signal also the data clock is included. This can be recovered

by the receiver for synchronization. Figure 6 shows an example of a Manchester coded signal. For more details take a look at [5]

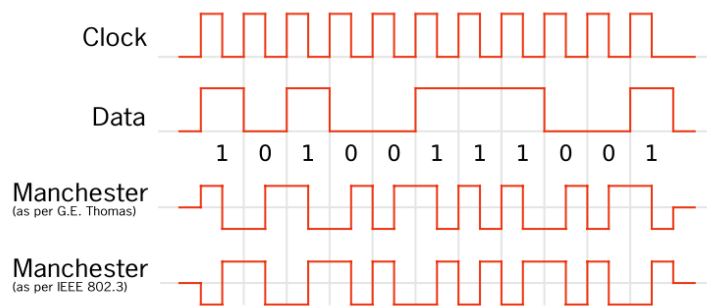


Figure 6: Example of a Manchester coded signal

The required bandwidth is then given by

$$B = 2 * \text{data rate} \quad (7)$$

### Example 3.2

The data rate of a Manchester coded signal should be given by

$$B = 3 \text{ kBd}$$

The minimum bandwidth of the OOK signal is then given by equation 7:

$$B = 2 * 3 \text{ kBd} = \underline{\underline{6 \text{ kHz}}}$$

This bandwidth of 6 kHz is the minimum required bandwidth of the tank circuit.

## 3.2 Q Factor and signal bandwidth

Now let's take a look to the Q factor for a given data signal. This is important, while the Q factor reduces the bandwidth to a given center frequency and therefore reduces the sensitivity of the system.

In section 3.1 on the preceding page it is shown, which bandwidth is occupied for a specific signal. Let's take a look to an example.

**Example 3.3**

A Manchester coded signal should be received by a parallel tank circuit. What is the maximum allowed Q factor for the tank circuit? The parameters are:

- center frequency  $f = 125 \text{ kHz}$
- data rate  $n = 4 \text{ kBd}$
- Manchester coded

With equation 7 on the previous page the needed bandwidth is

$$B = 2 * 4 \text{ kBd} = 8 \text{ kHz}$$

With equation 3 on page 6 now the Q factor is given by

$$Q = \frac{125 \text{ kHz}}{8 \text{ kHz}} \approx \underline{\underline{15,6}}$$

The Q factor calculated in example 3.3 is the maximum allowed Q factor for the tank circuit. The tank circuit works like a filter for the received signal. If the Q factor is higher than this value, the tank circuit can't receive the signal with a good quality. For an accurate demodulation, it's important, that at least the zero harmonics of the sidebands is received. Otherwise the modulation index will be decreasing and the sensitivity will also be decreasing. The information is included in the sidebands of the received signal.

On the other hand, if the Q factor is too low, than the filter characteristic of the tank circuit is too poor. In this case an outband disturber can have a negative influence. Additionally the voltage on the AS3932 inputs can be too low.

**3.2.1 Major disturber in Germany**

In Germany there are some regions with big transmitters, which can significantly decrease the system performance, as they are working in the same range as the AS3932. This is a list of some transmitters. More can be found at [1]<sup>1</sup>:

**1. DCF42**

This signal is used for Differential GPS. It works on 122,5 kHz and 123,7 kHz with a bandwidth of 9 kHz. The transmitter is located in Mainflingen near Frankfurt/Main.

**2. DCF49**

This is a special signal to control electrical consumer units. It is mainly used by some energy supplier. It works on 129,1 kHz. This transmitter is also located in Mainflingen.

<sup>1</sup>Sorry, this page is available only in German

## 4 Basics for Coil design

The coil design for the tank circuits can be reduced to a construction problem, as shown in this section. This can be done, as we are in the near field of the transmitter antenna.

### Definition 4.1 (Near field)

The near field and far field are regions around an antenna. The boundary between them are vaguely defined. Roughly speaking, the near field is the region with a radius  $r$  given by

$$r \ll \lambda \quad (8)$$

with the wavelength  $\lambda$  given by

$$\lambda = \frac{c}{f} \quad (9)$$

where

$c$  speed of light

$f$  frequency of the signal

See [6]

### Definition 4.2 (AS3932 works in the near field)

At a frequency of 125 kHz the wavelength  $\lambda$  is given by equation 9

$$\lambda = \frac{3 * 10^8 \frac{m}{s}}{125 \text{ kHz}} = \underline{\underline{2400 \text{ m}}}$$

As the AS3932 is designed for ranges up to 10-15m, one can see, that the AS3932 is always working in the near field.

In case of a near field only the magnetic component of the electromagnetic field has to be considered for the coil design. To have a good starting point lets take a look to the device and system specifications. The data sheet shows a minimum required voltage on the receiver input. This can be defined as the minimum required induced voltage in the inductance of the tank circuit at resonance frequency.

Now we can define some hints for the design:

1. **The value of the magnetic field strength is given at the maximum distance between the transmitter and the receiver:**

In this case the number of turns and the diameter of the coil can be calculated.

## 2. The maximum diameter of the coil is given due to mechanical restrictions:

In case that the minimum magnetic field strength is also given, the number of turns can be calculated. Otherwise the required minimum magnetic field strength can also be calculated.

The most important parameter for the tank circuit, which results in a good performance of the system, is the geometry of the coil, not the absolute inductance of the coil. The inductance depends on the geometry and is therefore a parameter, which results from the design. It should not be defined before as a requirement.

## 4.1 Induced voltage

### 4.1.1 Air coil

The peak value of the induced voltage  $\hat{u}$  in an tank circuit is given by

$$\hat{u} = 2\pi f N \hat{B} A Q \quad (10)$$

with:

$f$  Frequency of the magnetic field given in [Hz]

$\hat{B}$  Peak value of the magnetic field given in [T]

$A$  Geometric size inside the coil given in [m<sup>2</sup>]

$N$  Number of turns of the coil

$Q$  Q factor of the tank circuit

---

### Example 4.1

A tank circuit with an air coil is given by

- $N = 110$
- $A = 10 \text{ cm}^2$
- $Q = 10$

The signal, which should be received, is given by

- $f = 125 \text{ kHz}$
- $\hat{B} = 5 \text{ nT}$

The induced voltage becomes than

$$\hat{u} = 2\pi * 125 \text{ kHz} * 5 \text{ nT} * 110 * 10 \text{ cm}^2 * 10 \approx \underline{\underline{4,3 \text{ mV}}}$$


---

### 4.1.2 Ferromagnetic Core

If there is a ferromagnetic core inside the coil, the peak value of the induced voltage  $\hat{u}$  is given by

$$\hat{u} = 2\pi f \mu_r N \hat{B} A Q \quad (11)$$

with:

$f$  Frequency of the magnetic field given in [Hz]

$\hat{B}$  Peak value of the magnetic field given in [T]

$A$  Geometric size inside the coil given in [m<sup>2</sup>]

$N$  Number of turns of the coil

$Q$  Q factor of the tank circuit

$\mu_r$  Relative permeability of core material

The relative permeability  $\mu_r$  is similar to a magnification of the geometric size of the coil.

---

#### Example 4.2

A tank circuit with ferromagnetic core is given by

- $N = 200$
- $A = 4 \text{ mm}^2$
- $\mu_r = 300$
- $Q = 8$

The signal, which should be received, is given by

- $f = 125 \text{ kHz}$
- $\hat{B} = 1 \text{ nT}$

The induced voltage becomes than

$$\hat{u} = 2\pi * 125 \text{ kHz} * 1 \text{ nT} * 200 * 4 \text{ mm}^2 * 300 \approx \underline{\underline{1,5 \text{ mV}}}$$


---

## 4.2 Inductance of the coil

Now follows a description, how the inductance can be calculated from the given geometry.



### 4.2.1 Air coil

An air coil can be seen as a flat spiral coil. Then the inductance is given by

$$L = \frac{r^2 N^2}{(2r + 2.8d) * 10^5} \quad (12)$$

with

$L$  inductance [H]

$r$  mean radius of coil [m]

$N$  number of turns

$d$  depth of coil (outer radius minus inner radius) [m]

For more informations see [4].

### 4.2.2 Ferromagnetic core

With a ferromagnetic core the design of the coil is a cylindrical coil. For this the inductance is given by

$$L = \frac{\mu_0 \mu_r N^2 A}{l} \quad (13)$$

with

$L$  inductance in Henries [H]

$\mu_0$  permeability of free space [ $4\pi * 10^{-7} \frac{H}{m}$ ]

$\mu_r$  relative permeability of the ferromagnetic core

$N$  number of turns

$A$  area of cross-section of the coil in square meters [ $m^2$ ]

$l$  length of coil in meters [m]

For more informations see [3].

## 4.3 Parasitics

Every real coil looks more like the circuit of figure 7 on the next page.

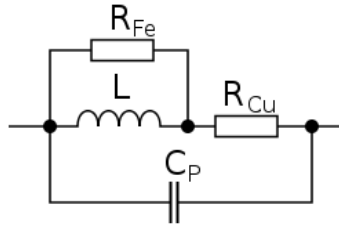


Figure 7: Real coil

The parasitics shown in figure 7 have also influence on the sensitivity and performance of the AS3932.

The resistor  $R_{Cu}$  reduces the Q factor of the tank circuit. For a high Q factor the resistance should be low.

The parallel capacitor  $C_P$  defines a resonance frequency of the coil. This resonance frequency should be as high as possible, so the capacitance has to be low.

## 5 Tank circuit design

Now it should be clear, that it is a good idea, to start the tank circuit design with a first look at the given data rate. This data rate defines the maximum allowed Q factor for the tank circuit.

The next point is the sensitivity of the AS3932, which defines the required geometry and the required field strength at the maximum distance the coils. But here is a little problem: We have an equation system with two variables and only one equation.

One solution for this can be that the geometry will be defined first. With this definition the minimum required field strength for the system at maximum distance is given.

Another solution can be that the minimum field strength is defined, which then defines the required geometry for the coils.

If the minimum field strength at the maximum distance is defined then the required field strength at the transmitter can be calculated. Vice versa, if the transmitter field strength is defined, the maximum distance can be calculated.

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