# *APPLICATION NOTE III*

## *IPM-165 – a universal Low Cost K-Band Transceiver for Motion Detection in various Applications*

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# IPM 165 – a universal Low-Cost K-Band Transceiver for Motion Detection in various Applications

## - Application Note AN 03 -

## 1. Introduction

The mono transceiver IPM 165 from InnoSenT has been designed into various applications and markets and is highly appreciated for its attractive price, its small dimensions, its high sensitivity and its possibility of universal applications.

*Product Picture* *Mechanical Outlines* *Pin Description / Antenna pattern*

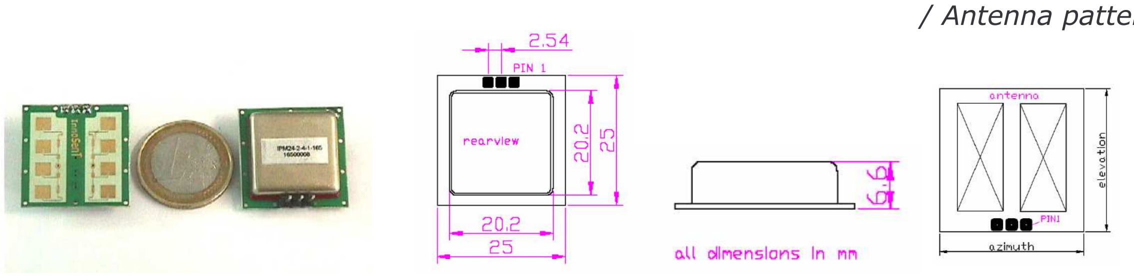


Fig 1: Photograph and dimensions of K-band transceiver IPM 165

This note shall facilitate the user, to design this component into various applications. Besides the usual CW (continuous wave) - mode the possibility of pulsing is described. Signal processing circuitry becomes pretty simple because of the straight-forward architecture and enables the user to build cost efficient and compact radar detectors.

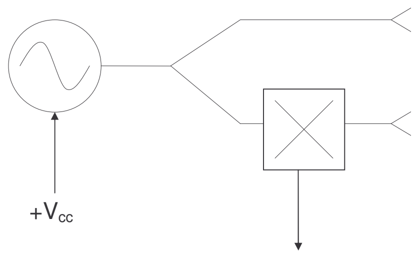


Fig 2: Block diagram of the IPM 165

The circuitries discussed here should meet most of the requirements as they occur in applications like door opening, intrusion alarm and security, machine and equipment control, sanitary equipment and sports and toys applications. Basic rule is that the sensor has to detect and monitor the **movement** or **motion** of an object. These so-called "objects" might be passive items, vehicles, animals or human beings which are moving more or less quickly. The correct circuitry will detect a motion down to quasi still-standing.

Virtually stationary objects cannot be detected by the IPM 165, as also the direction of the motion can't be determined by this simple module without additional circuitry offered by sensors with stereo (dual channel) architecture.

On the other side the sensor impresses by outstanding sensitivity. A human being i.e. can easily be seen in a range up to 15 or 20m or even beyond. Therefore this sensor is perfectly suited for so-called dual-technology solutions in security applications, where the advantages of PIR (passive infrared) and radar detectors are supporting each other.
Just as an example radar and PIR detectors perform actually vice versa when an object is moving towards or around the sensor. While a PIR detector is rather insensitive to motions direct and straight towards or away from the sensor, the radar detector

performs best there and with highest available sensitivity. If the object is moving pretty much on a circle around the sensor with a constant distance it is the other way round. The radar sensor loses sensitivity because of the missing Doppler signal, while the PIR sensor shows its best sensitivity because of the rapid change of the temperature image.

The IPM 165 can be perfectly operated with very short pulses and high pulse pause to pulse length ratio. Therefore options become attractive like fast amplitude modulation and saving in current consumption by keeping the average operating current low (operation with battery and/or solar panel buffered supplies), see more information about that in paragraph 5.1.

## 2. Description of the IPM 165

The IPM 165 represents a highly integrated radar sensor including transmit and receive antennae, a transmit and a receiver part. It requires one single polarity power supply only. It is available as a 3V and 5V operating voltage version.

The outstanding sensitivity is possible by two design features:

- the usage of separate transmit and receive paths and antennae respectively
- the usage of a balanced mixer

Sophisticated circuitry design and the selection of proper components enable the user to operate the IPM without additional temperature compensation methods and meeting the ETSI frequency standards at the same time. Therefore the IPM 165 has got a generic CE approval and certification.

Extracts from the IPM 165 data sheet:

| Parameter | Symbol | min. | typ. | max. | Units | Comment | |
|---|---|---|---|---|---|---|---|
| transmit frequency | f | 24.000 | 24.125 | 24.250 | GHz | meeting ETSI #300 440 | |
| output power (EIRP) | $P_{out}$ | | 16 | + 20 | dBm | meeting ETSI #300 440 | |
| temperature drift | $\Delta f$ | | 900 | | kHz/°C | | |
| antenna pattern | horizontal | | 80 | | ° | azimuth | model 165 |
| | vertical | | 32 | | ° | elevation | |
| side lobe suppr. | horizontal | | 13 | | dB | azimuth | |
| | vertical | | 13 | | dB | elevation | |
| antenna pattern | horizontal | | 70 | | ° | azimuth | model 170 |
| | vertical | | 70 | | ° | elevation | |
| side lobe suppr. | horizontal | | 13 | | dB | azimuth | |
| | vertical | | 13 | | dB | elevation | |
| IF output | voltage offset | -300 | | 300 | mV | | |
| supply voltage | $V_{CC}$ | 4.75 | | 5 | V | | |
| supply current | I | | 30 | 40 | mA | continuous operation | |
| operating temperature | $T_{OP}$ | -20 | | +60 | °C | | |
| outline dimens. | ~ 25 x 25 x 7 | | | | mm | preliminary | |

A few more remarks regarding the IPM 165:

The antenna patterns of the transmit and the receive antennae are identical and rather broad to be able to detect within a pretty large angle.

The total current consumption happens exclusively in the transmit part. The given minimum operating current cannot be lowered decreasing the supply voltage without taking the risk of a malfunction at certain temperatures. Therefore other methods have to be used when trying to lower the current consumption (see paragraph 5).

The signal available at the unit output is sinusodial for a monotonously moving object and will provide very low signal amplitude (in the dimension of 300 µV). Therefore it must be amplified immediately with high input impedance and lowest noise contribution. The load impedance of the amplifier can be high because the internal and integrated load resistance is middle-ohmic. Without additional external amplification a radarsensor cannot be simply checked with a scope since no signal can be seen on the screen because of missing scope sensitivity for such signal levels.

## 3. Handling precautions – ESD sensitivity

**Attention please!** Transceivers of this architecture with direct access to the mixer output are definitely **ESD sensitive**. Make sure personnel who is handling an individual unit, not yet mounted onto a motherboard and equipment like soldering irons are protected properly according to ESD recommendations. It starts already when taking the units out of the sealed package. **Never** touch or grap the sensor at the **connector pins**, but only at the edges or corners of the device.

As soon as the device has been assembled and soldered into the surrounding circuitry the danger is gone except for stressing the mixer part directly with higher voltage than 3 kV. External components like varistors don't provide proper protection since the mixer diodes are the fastest fuse you can find!

## 4. LF-amplifier circuitry

The load of the signal output and the following amplification of the mixer output signal is usually done by operational amplifier stages, which are providing both – amplification and bandwidth limitation.
Depending on the application the total required amount of external amplification can be somewhat around 70 to 80 dB, in order to get the mixer output signal into an amplitude range of 1V.
Generally the bandwidth of the receiver mixer of the IPM 165 is pretty high – at least 100 MHz. However in order to build a highly sensitive detector for a certain application it is heavily recommended to limit the bandwidth of the amplified frequency band and therefore avoid injection of unwanted noise.
The frequencies of the signals expected at the mixer output can be easily estimated by the following famous "Doppler" formula:

$$f_D = 2 f_0 \cdot \frac{v}{c_0} \cdot \cos\alpha$$

It means

$f_D$ Doppler frequency
$f_0$ transmit frequency
$v$ velocity of the moving object or the sensor relative to the object
$c_0$ velocity of light
$\alpha$ angle between the motion vector and the straight line object - sensor

For the nominal transmit frequency of 24.125 GHz the following rule of thumb applies

$$f_D = 44 \frac{Hz}{km/h} \quad \text{or} \quad f_D = 69 \frac{Hz}{mile/h}$$

When detecting humans only, the filter bandwidth may be limited to 6 to 600 Hz.

Inside rooms with light emitting lamps using discharge like neon lights in Europe a sharp filter is required for the 100 Hz spectral line.

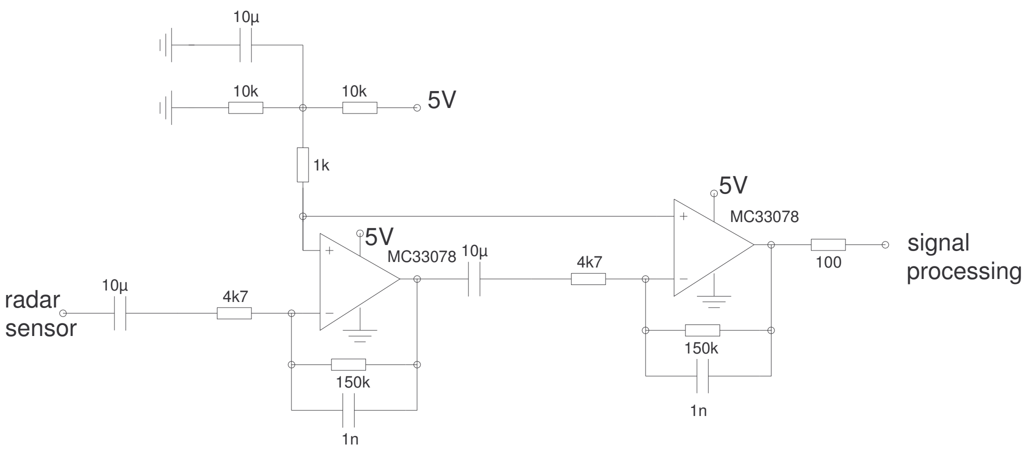


Fig 3: recommended schematic of a LF amplifier with 6…600 Hz bandwidth and 60dB gain

It has to be noted that if the opportunity exists to increase the capacitance values of the capacitors used by let's say a factor of 10, the Ohm values of the relevant resistors might be decreased by a factor of 10, which will help to improve the noise performance and therefore sensitivity.

In this recommendation a DC coupling of the signals is used. This avoids any problems of variations in production.

Basically the mixer output will show a DC offset, which can be used for a self-test of the unit. However you have to be aware of the following:

Ideally the DC offset at the mixer output would be ZERO for an IPM 165, since we are using anti-parallel mixer diodes. As discrete mixer diodes are never exactly equal in DC characteristics, a differential DC level can be found, which can be negative or positive and may vary up to 200 mV. Just this side effect can be used for the self-test.

To take advantage of that you add a first DC-coupled amplifier stage of low gain like 20 dB or factor 10, de-couple this signal and then continue to amplify with AC-coupled stages with the balance of 50 to 60 dB of gain.

## 5. Pulsing of the transceiver

### 5.1 Oscillator starting performance – pulse length

It is virtually simple enough to pulse the IPM 165 by its supply voltage. There are 2 reasons for pulsing a sensor

- to generate an amplitude modulation with 100% modulation depth
- to save average current

Very fast pulsing or modulation of an oscillator is only achievable, if the oscillator starts oscillating fast enough when applying the supply voltage. The following screen shots prove, that the transmit oscillator of the 165 is really starting rapidly.

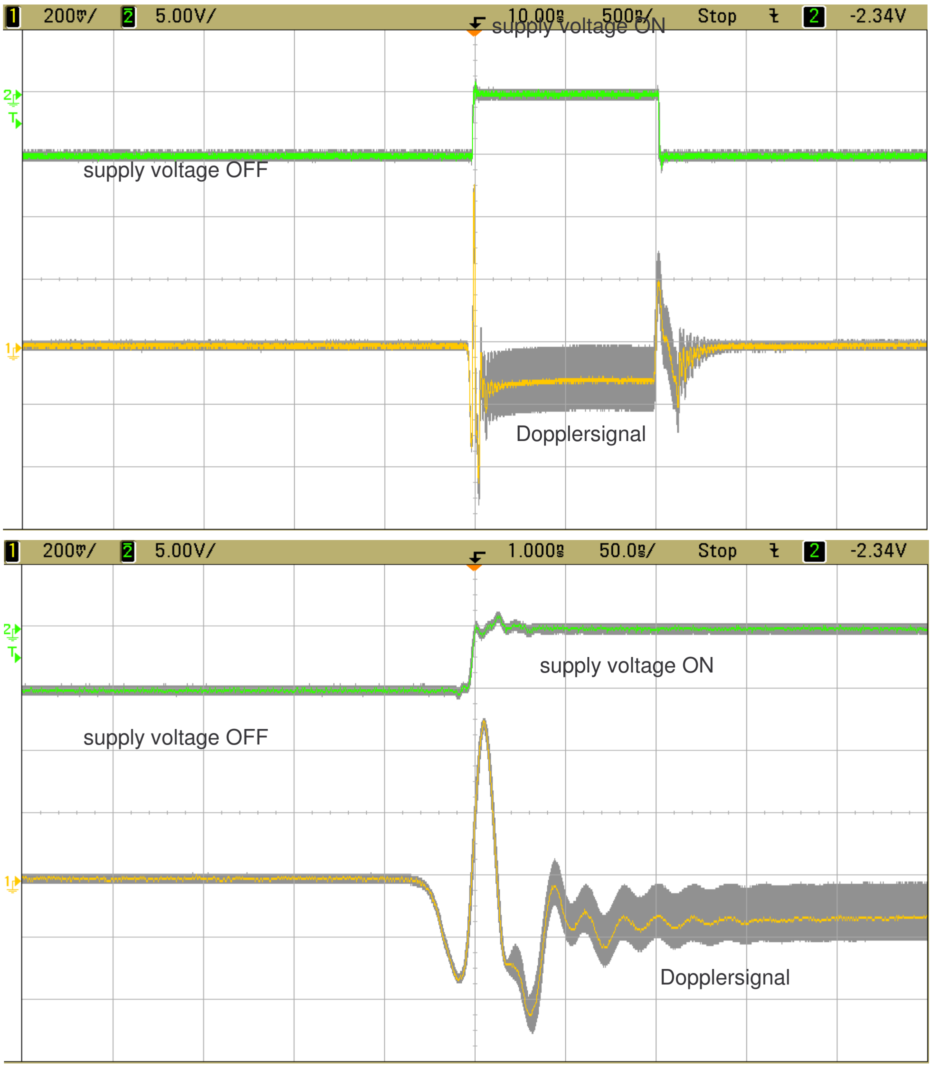


Fig 4: Starting performance of an IPM 165 by fast pulsing the supply voltage with 1µsec pulse

above: time scale 500 nsec/div
below: time scale 50 nsec/div

Obviously transmitter and receiver both start within 100 nsec, while the switch-OFF time may take 200 nsec.
In order to be on the safe side (variations in production) we recommend **not to decrease** the pulse length below **1 µsec.**
If pulsing the voltage supply is used for current saving, the pulsing must be selected carefully to re-generate the Doppler signal. According to Shannon's sampling theory a signal of frequency f has to be sampled at least with double the frequency for correct re-construction.

**Example:**

In an intrusion alarm application sampling the frequency range (i.e. 5….500 Hz) of the Doppler signal generated by a human being requires at least 1000 Hz as sampling rate corresponding to 1 msec. A pulse / pause ratio of 1:1000 results in a reduction of the average current by a factor of 1000. This leads to the above mentioned minimum pulse length of 1 µsec.

## 5.2 Pulse circuitry for IPM 165

Pulsing the supply voltage can be done simply by switching a MOSFET.

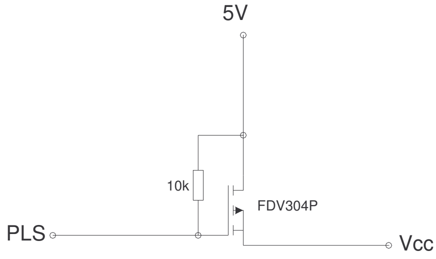


Fig 5: pulse circuitry for the IPM 165

The pulse can be applied by a CMOS or TTL gate circuit.

## 6. Frequency hopping method by switching of the supply voltage

## 6. 1 Frequency pushing by supply voltage

Each oscillator will change its oscillation frequency when its supply voltage changes. The change depends on how the frequency is generated. Since the frequency stabilisation of the IPM 165 is rather simple, the change of operating frequency is in the area of a few MHz when changing the supply voltage up to 10%.

By the way this effect has to be considered when stabilizing the supply voltage by an integrated voltage regulator, which provides the output voltage within certain specified limits. Decreasing the supply voltage beyond 10% to lower values is not recommended since the start of oscillation at temperature extremes might be influenced or even prohibited.


Fig 6: Oscillation frequency change as function of supply voltage for an IPM-165

As an example a change in supply voltage by 5% causes a change in oscillation frequency of about 6 MHz.

We must point out that the frequency pushing effect varies from module to module. The variation of oscillation frequency has its root cause in the variation of the transmit transistor impedance. Therefore InnoSenT cannot guarantee a specification for frequency pushing. It is therefore recommended to use this effect for frequency variation only if the absolute value of frequency change over voltage supply is uncritical.

## 6.2 Frequency shift keying (FSK)

The effect of frequency pushing mentioned can be used for frequency shift keying (FSK) modulation, a way of frequency hopping. Again the comment that the modulation change varies from module to module. Fig. 7 shows the very cleane spectrum of a FSK-modulated IPM 165, where a modulation change of about 2.5 MHz was generated by pulsing the supply voltage.

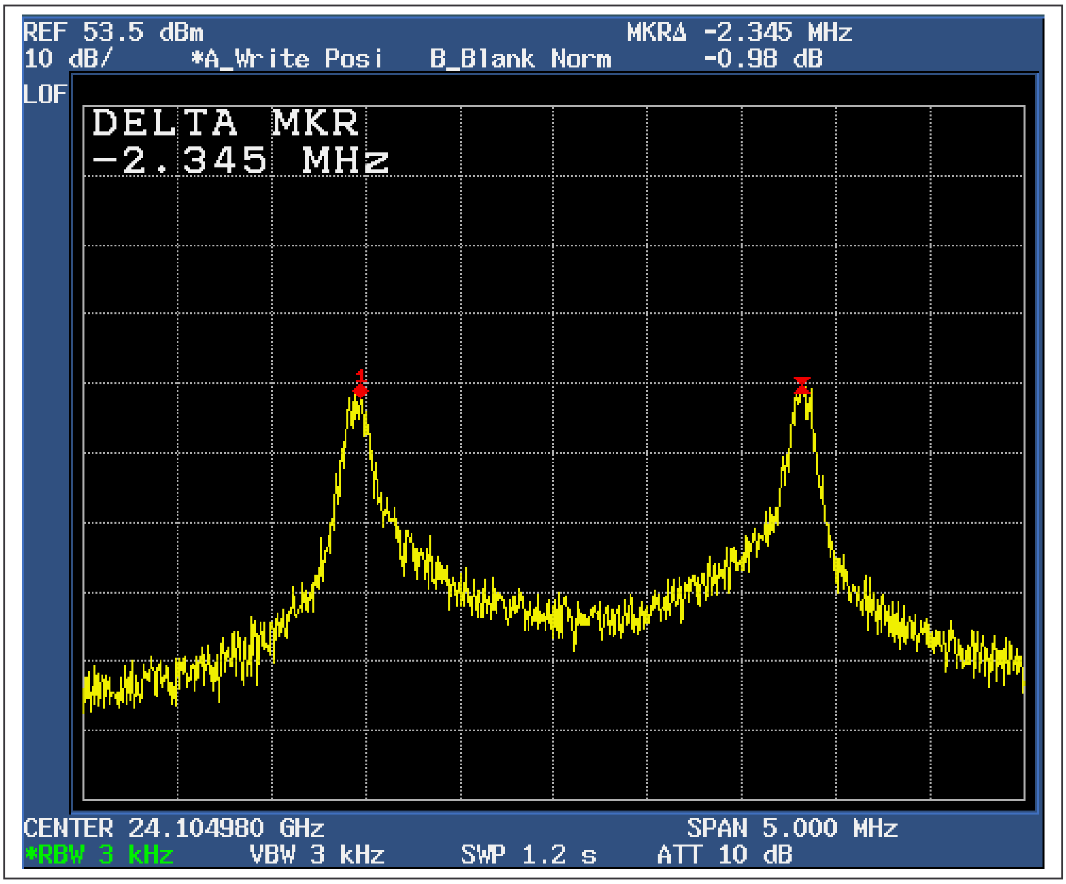


Fig 7: frequency spectrum of FSK-modulated IPM 165, generated by switching the supply voltage.

We recommend the following switching circuitry:

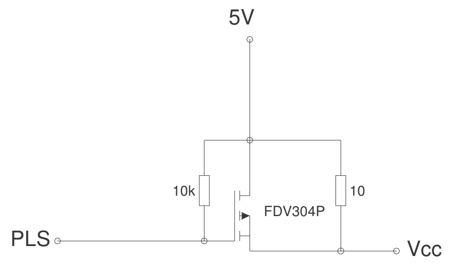


Fig 8: Recommended circuitry for FSK modulation of an IPM 165 by switching the supply voltage. Pulse generation can be done by a CMOS or TTL gate circuit.

In this schematic the supply voltage is switched between the full voltage available from the supply and a value reduced by the voltage drop generated by the operating current (about 30mA). Since this operating current varies from module to module, also this voltage variation is subject to production variations.

In the literature this method is mentioned to detect the direction of a motion by FSK. In this case the phases of the two Doppler signals generated by two different transmit frequencies have to be evaluated for its sign. In our opinion the effort for that is much higher and will be dependent on production variation compared with the solution using a stereo (dual channel) module (i.e. IPS 154 from InnoSenT).

There is an opportunity to frequency-modulate the module with a triangle or sawtooth signal applied to the supply voltage. Some sort of range gating can be achieved, always keeping in mind that the production variations will be limiting the performance. An introduction to frequency modulation of radar modules is available as our application note AN2 “Detection of moving and stationary objects”

## 7. Operating module IPM 165 for the first time!

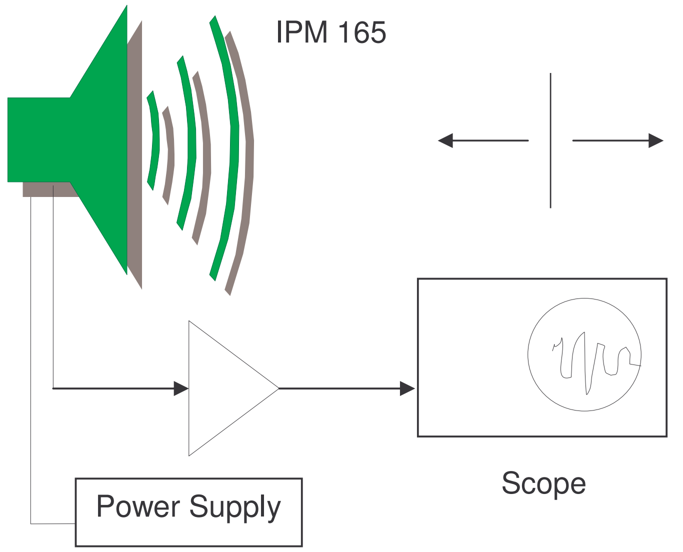


Fig 9: Circuitry for functional test of a IPM 165

- Be sure you apply the correct supply voltage to the module (plus 5 or plus 3V)
- Connect the module output with a low frequency amplifier with at least 60 dB gain before feeding the input of a scope with a sensitivity of at least 50 mV/division.
- Move your hand in about 60 cm to 1m (2 to 3 feet) distance in front of the antenna.
- You should see a sinusoidal, not frequency-constant, but clean signal on the scope screen providing a good signal/noise ratio
- For a more professional investigation and analysis you may purchase InnoSenT's Dopplersimulator IDS 208 (contact by tel. 49-9528-9518-84).
  This device simulates a monotonously moving object in one direction by electronic means, with which you can test the radar module. Other simple test methods may also be fine for a first glance like a turning fan.
- You may optimize your radar sensor by changing the gain of your LF amplifier and by adjusting the amplifier bandwidth.
- Operating the radar sensor close to neon lights the generated 100 Hz interference signal must be thoroughly filtered out.

## 8. Trouble shooting – just in case ...........

We presume you have connected your IPM 165 module according to fig. 9.

*1. case: an output signal is definitely not existing – zero amplitude!*

- The well-known answer: did you connect the supply voltage correctly – correct polarity? The module hasn't got any polarity protection!
- Is your low frequency amplifier operating perfectly?
- Is the scope input sensitivity set to the correct, while lowest value?

*2. case: The output shows a pretty noisy signal while your movements in front of the sensor just generate no signals at all or only a weak sinusodial signal*

In this case the probability is pretty high, that the internal mixer diodes have suffered from an exposure by ESD and have been damaged. Repair impossible, a new sensor is due! Next time, please pay more attention when unpacking and mounting.

*3. case: the output does show a clean sinusodial signal, but with very low amplitude*

- Are gain and bandwidth of your LF-amplifier correct?
- You are moving your hands outside the antenna pattern of the sensor.

*4. case: The output shows a strong, constant signal with single frequency*

- Try to calculate the frequency of the signal. Do you find neon lights nearby if the signal is 100 Hz and you haven't implemented special filtering?
- Any other electrical interferer? Connecting cables to power supply, LF-amplifier and scope too long and causing instability?
- Mechanical interference by rotating parts, i.e. a fan in summertime, which might be operating as a reflecting and moving object generating a Doppler signal?

**We wish you good luck and success using the IPM 165!**

**Your InnoSenT-Team**

**Don't hesitate to contact us directly if you got further questions!**