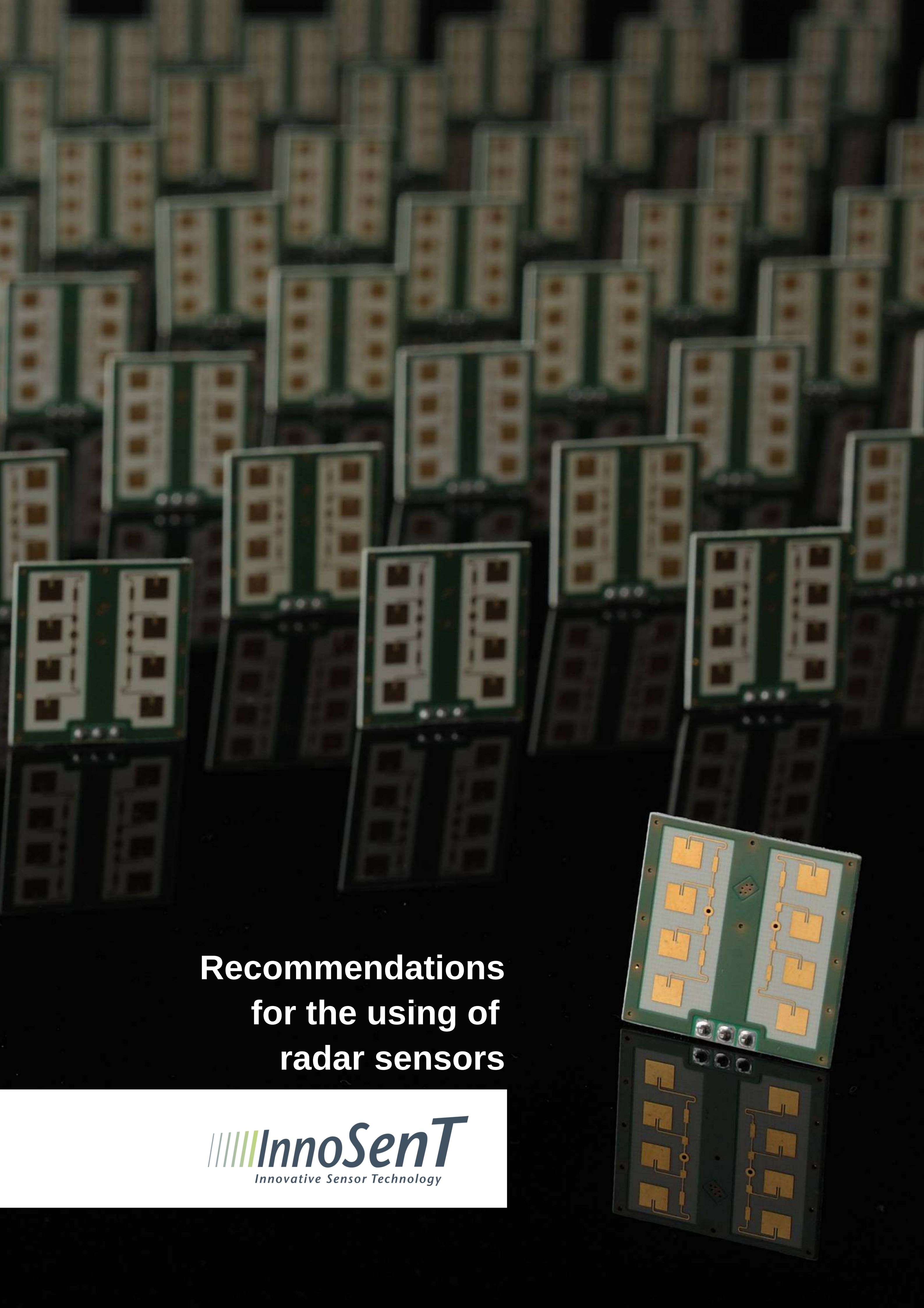

Recommendations for the using of radar sensors

InnoSenT
Innovative Sensor Technology

Recommendations for the usage of radar sensors in general and specifically for low cost devices (IPM 165)

1. General remarks

Radar sensors are generally used in huge quantities in order to detect motions and the position of objects remotely. Radar sensors are operated at high frequencies in the microwave region, while InnoSenT products mainly use the 24 GHz ISM band. Those sensors include passive standard components like SMD chip capacitors and resistors or multi-layer boards and at the same time active components like microwave Schottky diodes, PHEMT's (GaAs FET's), PIN diodes, Si-bipolar transistors and nowadays microwave IC's called MMIC's. All mentioned devices are subject to manufacturing tolerances, which become obvious after a circuit has been assembled.
These variations in specs may at worst add up or multiply or at best compensate and balance out. The topic of this article is to inform the user about characteristics of such microwave devices in order to avoid disappointment and surprises when using these parts in volume.

2. What might be the reason if we hear a statement like: "It doesn't work!"

Bad enough to say we are quite often confronted with the statement of a new customer after having completed the assembly of his first series production run: "Your radar sensors don't work! I can only use 50 percent of them while the first 10 prototypes were working so nicely!" When returning a couple of those "non-working" devices to us for a re-test, in almost all cases we find them working perfectly and passing our end-of-line test without any problem.

What's the reason for that? Simple answer: this customer and InnoSenT as a manufacturer are victims of the probability distribution in this world! 10.000 devices do perform differently than 10 samples. This has nothing to do with bad quality in production.

You may virtually rate the following as bad manufacturing quality:

- device does not work at all, in other words despite being operated with the correct supply voltage (mostly plus 5 V) the device does not draw any current or is short-circuited
- device shows mechanical damage – lid is broken or assembled improperly
- connector pins damaged.

Normally damages like these will be detected by InnoSenT during the 100% end-of-line test, therefore those parts won't end up at the customer. Should this unexpectedly be the case, InnoSenT shall replace such a device without any question.
For the very last item there might be damage during transportation. InnoSenT has invested considerably in developing materials to correctly pack devices avoiding transportation damages.

Actually it is much more delicate, if there is a possibility of a customer's error. Example: excess supply voltage or wrong polarity. Such errors can be identified – not always – but in many cases by the failure mechanism of a semiconductor.

Even more sensitive is the item "ESD damage of the receiver output" for sensors like the IPM 165, where you have access to the sensitive Si-Schottky mixer diodes. Those damages are recognized as:

- ♦ increased and strong noise floor of the receiver output
- ♦ strong and different amplitudes of noise of one of the 2 receiver outputs of stereo modules
- ♦ totally missing output signal while all DC parameters like supply voltage and supply current are in the predicted range.

These cases are specifically unpleasant, since the detection and proof is relatively easy for us as a manufacturer and we have to explain this to our customer.

Therefore: Don't let it get that far!

- ♦ Although our sensor outputs are internally protected by 470 or 1000 ohm bypass resistors, always use ESD protection as long as the devices haven't been placed and assembled in a circuitry
- ♦ As soon as devices have been inserted and soldered into the circuitry, there should be no danger anymore for ESD damage.
- ♦ **Just get used to the fact to always grap circuits at the corners or edges of the board, but definitely not at connector pins! If you simply watch this advice, you should never have any trouble with ESD damages!**

The most alarming comment from a customer is:

"Sensor does and doesn't work or in other words doesn't work as expected. As an example the detecting range is limited to 1m."

We should focus on such comments for the following lines.

3. What is considered as laws of physics and what is related to quality in production?

Quality in production has been elaborated already and this item can be closed, since in most cases you will find significant signs and marks on the product itself. By the way, each of our products is subject to our SPC system, which means even low cost sensors can be tracked individually. You may imagine the size of our data base where those data are stored.

If it is not a matter of quality in production, what other facts may contribute?

As said before, as a manufacturer we must know about and live with the **laws of physics** of semiconductor devices and the results of their statistical distribution.

Environmental influences like temperature and humidity are rather simple contributors, because we can evaluate those during a qualification process. The good news is that you as a customer can be sure that a new product does not become a product before it has not successfully passed a **qualification process** of roughly 4 months at the InnoSenT factory. During this process a representative number of modules go through numerous tests like long term increased temperature storage operational/non-operational, slow/fast temperature cycling at dry/humid heat, behaviour under shock and vibration etc.

We are now considering the impacts of physical parameters like the drain saturation current of a GaAs-FET, the tuning slope of a tuning varactor in a VCO, the noise figure of a pre-amplifier transistor, the dependence of the output voltage of a mixer diode as function of RF input signal, while the diode is operating additionally and unavoidably as a temperature sensor etc. etc.

An important physical parameter is the rectifier characteristics of a diode, which determines the value of the resulting DC-voltage versus an applied RF-power. It is different from diode to diode and represents the “fingerprint” of each diode.
This is just a short extract of possible parameters, which contribute to the overall assessment of a sensor. In this sense each individual microwave circuit is unique.

You may say: “Simple enough – screen!” We may buy key components from our subcontractors with restricted data! If ever possible – would you be willing to pay at least double the price for such a sensor? Definitely not!

Or we screen at our end-of-line test set-up – same result. The decreased yield will drive the price up considerably.

Therefore we want to take the chance to inform you about your possibilities even to drive your own circuitry up to a yield of ideal 100%.

4. Parameters of influence and solutions

4.1 DC parameters

Let's start with supply parameters. The main contributor to power consumption is the transmitter oscillator, which is assembled around a PHEMT (field effect transistor, used in almost all cases) or a Si-bipolar transistor or even an MMIC.

Supply voltage / supply current

In any case, please always stick to the specified and recommended supply voltage! Usual changes caused for instance by voltage regulators are harmless and have been evaluated by us. However you should avoid further-going changes - for instance in order to regulate or adjust the supply voltage to increase/decrease the oscillator output power. Firstly you will be changing the oscillator frequency (frequency pushing). Secondly you risk the safe operation of the semiconductor device when increasing the supply voltage and you risk the safe start of oscillation of the oscillator at all specified temperatures or frequencies (for a VCO) when lowering the supply voltage.

Unfortunately you (and we) don't have much influence on the supply current. This is resulting from the DC characteristics of the individual transistor, while for FET's the so-called saturated drain current is dominating. Regarding this parameter specifically GaAs-FET's show a wide spread, actually up to a factor of 4. Screening and selecting devices drive the cost up (see comment above).

DC offset voltage at the receiver output

InnoSenT uses basically balanced diode designs in their receiver paths, which brings an advantage regarding noise. Theoretically the resulting differential voltage at the receiver output should be ZERO, but only if both diodes are exactly identical and if there is no unbalance in the feeding RF network. In reality there will always be a small amount of a differential voltage which may have negative or positive polarity and may go up to values as high as plus/minus 300 mV. ***Neither the amount nor the polarity of this offset voltage is a mark of quality of a module.***

Some customers even use this offset voltage as a self test – good idea. You should just be aware of the failure mechanisms.

Offset voltage

- value is considerably higher than 300 mV – probably failure of one mixer diode
- exactly zero – oscillator failure or failure of both mixer diodes at the same time or exactly identical mixer diodes (very unlikely).

On top of that you may amplify this offset voltage by DC-coupling, however not more than by a factor of 10 (20dB), otherwise the following amplifier will be driven into saturation. From there on any amplification must be performed by AC-coupling (see following paragraph 4.3).

4.2 High frequency performance of the radar sensor

The nominal high frequency performance of a sensor is specified in its data sheet.

One of the most important specifications is the pattern of the transmit and receive antennas. In most cases InnoSenT uses separate transmit and receive antennas, which means a theoretical advantage of 3 dB versus one common transmit/receive antenna.

What does this spec ***„“antenna pattern beam width“*** mean? It does NOT mean that there is no transmission or reception beyond those lines. It just means that at this imaginary line the transmitted or the received energy had dropped to 50% of the boresight value. Quite often the erroneous opinion exists that the area beyond those lines is “in the middle of nowhere”!
A big object (metallic wall or car) will easily compensate the decreased antenna gain by its huge reflexion coefficient.

Another statement:
High transmit power does not automatically mean “sensitive radar”. We have to consider all possible combinations – high transmit power and high receiver sensitivity, high transmit power, but low receiver sensitivity and vice versa – low transmit power and low receiver sensitivity and low transmit power, but high receiver sensitivity. The expression “receiver sensitivity” has to be commented.

4.3 Sensitivity of a radar sensor

The question is how to define the “***sensitivity”*** of a radar.

The answer is simple enough: finally the so-called signal-to-noise-ratio counts! This means the gap of a receive signal caused by a defined reflexion target to the noise floor, in which by analogue signal processing no reasonable target extraction is possible anymore. Even a small receive signal will result in a good and sensitive sensor, if the noise floor is sufficiently far below the signal level.
Quite often customers interpret a high object signal as „high sensitivity“ while it has to be seen in relation to the noise floor gap. An object signal can be amplified easily and be brought into a certain range, while the same will happen to the noise floor as well. It is important, that your “decider circuitry” will not generate false alarms by amplified noise.

4.4 Frequency tunable/agile oscillators for FMCW/FSK applications, so-called VCO’s

For VCO’s the following statement is definitely more applicable – there are never 2 oscillators with exactly the same tuning curve frequency versus varactor/tuning voltage! Even so-called MMIC’s show a variety and spread, maybe to a lower extend.
The tuning curve depends on many parameters, not only the tuning varactor itself. Parameters like quality factor of the resonant circuitry, etching tolerances at coupling gaps, metallisation layer thickness, internal feedback capacitances of the oscillator transistor, its operating point etc. etc. have impact on tuning bandwidth and tuning slope.

For some products with internal VCO InnoSenT is providing test data for transmit frequency versus tuning voltage – at some additional cost of course due to the increased test effords.
You should talk to us in case you plan a volume production if you require such information.

4.5 Signal conditioning circuitry – signal amplification to generate an “alarm”

Some InnoSenT modules include internal LF amplification, mainly to provide ESD protection. Genericly applicable modules like the IPM-165 do not include internal amplifiers in order to provide you as end user enough flexibility regarding base bandwidth.

The amplifier chain following the mixer output fulfils 2 jobs:

- to generate an alarm in case a real object appears
- to limit the detected frequency range of the Doppler signal processing to avoid the detection of undesired objects.

It is mandatory to limit the filter characteristics of your amplifier chain. Doing this you easily gain sensitivity by lowering the noise floor level.

The lower frequency band limit is adjusted by changing the RC series coupling components between amplifier stages, while the upper frequency limit is changed by the RC combination in the feedback path of your opamp.

The circuitry can be laid out according to our application note ‘1 item 3.2.3. In general a total line-up amplification of 60 to 70 dB is required in order to bring a receiver signal of a few 100 µV’s right at the mixer output to a level of 1 to 2 Vpp, depending if you want to end up in a limited or a linearly amplified LF signal. As basic amplifier circuits you may use inverting or high-impedance non-inverting amplifier circuits. To guarantee lowest noise contribution you should select appropriate opamps.
Note: Avoid high ohmic resistor values in your feedback paths for noise contribution reasons. Gain your required amplifier gain by lowering the values of your interstage coupling resistors.

At th end of your amplifier chain you will certainly place a “decider” circuit, which generates an alarm signal, as soon as a certain threshold is exceeded.

Remark regarding paragraph 4.1: the very last 40 or 50 db of gain can only be generated by an AC-coupled approach, since a DC-coupled amplifier would be driven into saturation by the mixer DC offset.

This part of the LF circuitry requires your utmost attention. Actually errors in this approach is in most cases the root cause if **problems occur in volume production**!

5. Consequences for the layout of an amplifier circuitry

The amplitude of a radar receive signal is subject to severe variations due to lots of impacting physical parameters.

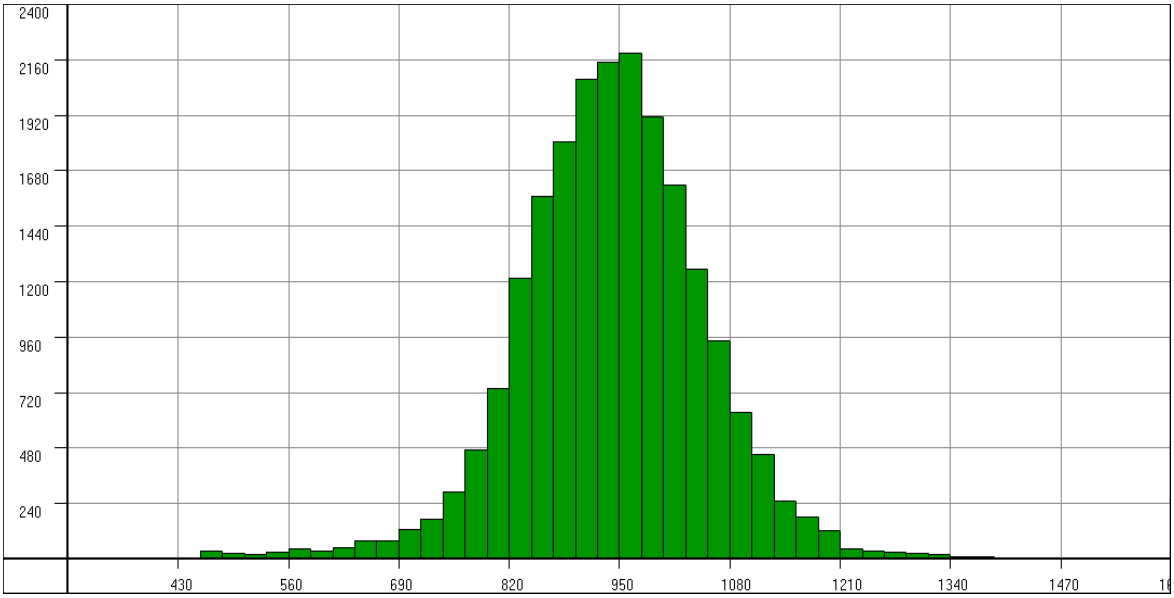

Fig. 1 Distribution of the sensor output voltage (X-axis in mV) over quantity (Y-axis) generated by a reference target (InnoSenT end-of-line test set-up)

A distribution of 20.762 manufactured sensors (manufactured within 12 working days) of part number IPM-165 is presented in the figure above. Each sensor has been illuminated using an electronic Doppler simulator (IDS 208 from InnoSenT) presenting a defined moving target, while the output signal amplitude was measured. The listed values are specific to the test set-up used and don’t represent generic validity.

The consequence is that a customer should know that the output signal strength of many sensors in volume is not necessarily concentrated in a very narrow slot. The distribution spread shows clearly that the greater part of the modules is located within plus/minus 20% however variations up to a factor of 3 are possible.
This is the reason why InnoSenT is delivering its mass product IPM-165 in 3 categories selected by amplude of output signal generated by one reference reflector. This enables the end-user to provide the correct amplifier stages for each category A, B or C, while a pre-test and gain adjustment in the customer’s circuit is no longer necessary.

Please watch out:

The probability of a module to belong to category A, B or C is given by the statistical distribution curve. Therefore it is NOT possible for InnoSenT to intentionally produce products of category A, B or C. It might happen that our production line can’t find devices of categories A and/or C for some period of time.

Summary:

Please do not draw conclusions regarding the behaviour of 100.000's of sensors having performed tests with 10 pcs only.

Layout your LF-signal conditioning circuitry that way

- **that you either plan a fixed and high amplifier gain in order to make sure the smallest receive signal triggers your alarm reliably, while higher signals drive the output into saturation or**
- **that you foresee ways of adjusting the amplifier chain gain by potentiometers or exchanging certain resistors**
- **Attention! Changes of gain-relevant components usually also change the frequency response and frequency limits**

Use and accept the offer of InnoSenT, to receive the IPM-165 selected into 3 categories.

The discussed changes and variations of the output signals are definitely not a quality problem, but caused by the physics of the internal components used in a sensor. If you are watching the items mentioned during the design of your LF-circuitry you should not see any problems when going into volume production.

Thank you very much for your patience when reading this article. Enjoy the design of your specific radar sensor circuitry!

If you have got further questions please don't hesitate to contact the InnoSenT team by phone 0049-(0)-9528-9518-0 or by email under info@innosent.de.

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