Design of an active sensor for mm-wave imaging sensor networks

[1]Nirav Desai, [2]Munkyo Seo, [3]Mark Rodwell
[1]Graduate Student, [2]Graduate Student, [3]Professor
Department of Electrical and Computer Engineering, University of California, Santa Barbara
[1]desai.nirav.12.09@gmail.com, [2]mkseo@ieee.org, [3]Rodwell@ece.ucsb.edu

***Abstract*—the design of a mm-wave transponder to be used in a mm-wave imaging sensor network is presented here. MM-wave imaging sensor networks are based on the principle of mm-wave range finding and localization. These networks are scalable and provide localization without the use of external technologies. Active transponders for mm-wave imaging sensor networks are similar to satellite transponders in their design and have similar design challenges. Stability of mm-wave active sensors is especially critical as they need to receive a low power signal and transmit a very high power signal which can get coupled to the receiver. The design of such an active sensor is presented here in this paper.**

***Index Terms*— mm-wave technology, active sensor, imaging sensor network, mm-wave imaging, satellite transponder**

I. INTRODUCTION

Multi-Hop Wireless Sensor Networks

Wireless Sensor Networks are being increasingly deployed for applications like weather monitoring, information collection, monitoring industrial plants, etc. Multi-hop wireless sensor networks are the networks of choice for most of these applications because of their ease of use. However, they have problems with scalability and location services. Typically, a node in a wireless sensor network would record information and transmit to the next nearest node with a destination address. The second node would then transfer information to the subsequent node based on various path finding algorithms. If GPS links are available, the information packets would have a location stamp on them or else they would have the origin sensor node number stamp on them.

II. MM-WAVE IMAGING SENSOR NETWORKS

However, multi-hop wireless sensor networks have problems with scalability as the transmit time to destination starts increasing as the number of nodes start increasing. The mm-wave imaging sensor networks have been developed to overcome the scalability problems of multi-hop wireless sensor networks. Here in, a central information collector will transmit a mm-wave beacon to the sensors on the field. The beam will be highly directional even for small antenna sizes due to the high frequency used. The directionality of the beam is used to localize individual sensors. A Pseudo-Random Bit Sequence is modulated on the 60GHz carrier and this sequence is used to determine the distance of the sensor from the collector. This does not require a GPS system. The individual sensors will receive this beacon, modulate it with the local data and transmit it back at a different frequency to avoid interference. A passive sensor network based on this topology has been developed with a range of 10 meters and reported in [1].

III. ACTIVE SENSOR FOR MM-WAVE IMAGING SENSOR NETWORK

The aim of this project was to develop an active sensor for the mm-wave imaging sensor network which would extend the range of the network to include Low Earth Orbit Satellites and drones flying over a field. The attached figure describes this sensor network topology. Typical applications for such high range active sensor networks would include border patrolling on land and sea. When at sea, the sensors could collect sonar data searching for underwater submarines and transmit it to an overhead drone or satellite.

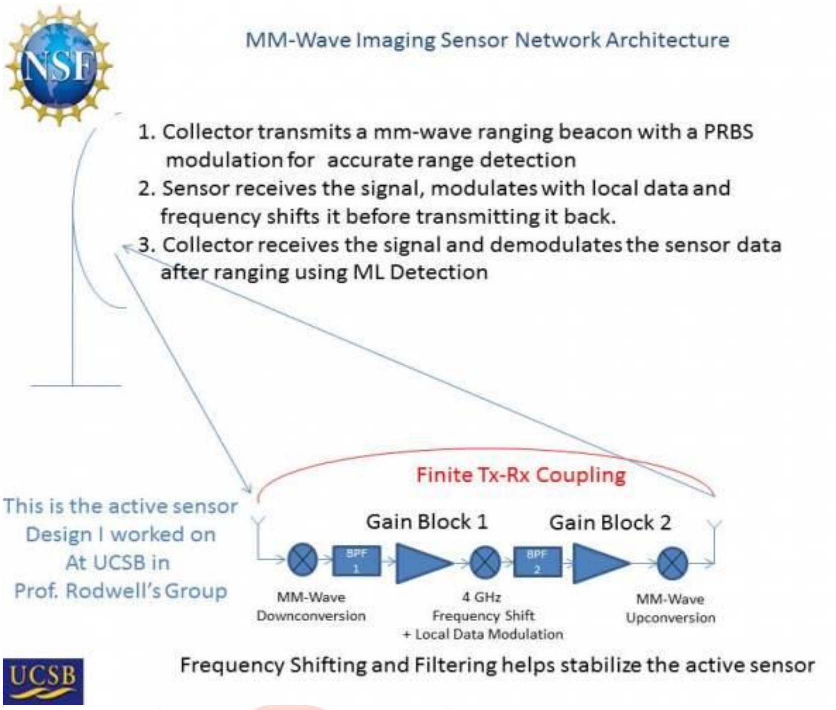

Figure 1: MM-Wave Imaging Sensor Network topology with passive sensor

IV. DESIGN OF ACTIVE SENSOR

The system design of the active sensor is exactly similar to that of a satellite transponder with the exact same requirements. It has to transmit a high power signal with local data to the collector and receive a low power signal with the PRBS from the collector. The interference between the high power transmitted signal and low power received signal has to be avoided by using different transmit and receive frequencies and filtering them at the transmitter and receiver.

Another potential problem with the design of the sensor deals with the stability of the sensor as there is a feedback loop from transmitter to receiver due to finite antenna isolation. The coupling between the transmitter and receiver sections leads to a feedback path as highlighted in figure 1. Although the frequencies are different, the mixing of reverse coupled transmitted frequency will produce the same frequency as that received from collector and make the sensor unstable. The design criterion to avoid this is given by:

Sensor Stability Equation

$$Sensor\ Gain\ \times Antenna\ Gain\ \times Antenna\ Isolation\ \times Filter\ Selectivity\ from\ passband\ to\ stop\ band < 1 \ldots (1)$$

This equation has to be applied to the reverse coupled path where there is mixing of sensor transmitted frequency to produce the frequency received from the collector. In order to ensure stability of the sensor in various scenarios of coupling between transmitter and receiver, a 20dB margin is typically added so that the above mentioned loop-gain has to be less than 0.01. For a given antenna isolation, filter selectivity and antenna gain, we will be able to find a value for the quantity sensor gain in (1). Half of this is this maximum allowed active gain on the sensor. The reason for this is that the signal passes through the sensor twice to complete the reverse coupled loop (1) from sensor transmitter to sensor receiver.

V. WIRELESS LINK DESIGN

The wireless link design is governed by the Frii's Equation for wireless communication given by:

$$P_T \cdot G_T \cdot G_R \cdot \frac{\lambda}{4\pi r^2} \cdot e^{-\alpha r} = P_R \ldots (2)$$

Where,

P_T = Collector transmitter power

P_R = Sensor received power

G_T = Collector transmitter antenna gain

G_R = Sensor receiver antenna gain

λ= Transmitted wavelength

r = distance from collector to sensor

α = Atmospheric attenuation constant which is dependent on frequency

The reverse link from the sensor to the collector is given by the same equation. The PRBS is modulated on the 60GHz transmitted beacon using Amplitude Shift Keying as it is required for coarse ranging and each bit value is not important. The local data from the sensor is modulated on to the received signal using Binary Phase Shift Keying which has a lower bit error rate than ASK for same power levels. The system is designed for a Bit Error Rate of 1E-3 using BPSK and this will set the required value of Eb/No at the receiver to 6.5dB. The noise power will have to be calculated for a bandwidth of 5 kHz and given receiver system hardware noise figure.

Noise power will be the sum total of the antenna noise and receiver system noise.

$Receiver\ Noise\ Power\ N_0\ = Antenna\ Noise + Receiver\ System\ Noise\ \ldots(3)$
$Antenna\ Noise = kT_{eq}R_sB\ \ldots(4)$
Where $k = 1.38 \times 10^{-23}$ J/K
T_{eq}= Equivalent Noise Temperature of Antenna
B = 3dB bandwidth of the antenna
$Receiver\ Noise = kT_0(\mathrm{F}-1)B_n\ \ldots(5)$
Where F = Receiver system noise figure
B_n = Receiver system bandwidth
T_0 = Receiver system temperature

The required received signal power and maximum allowed transmit power will set the requirement for sensor gain at a given range. Using high selectivity filters and tuned amplifiers which perform filtering of out of band signals, up to 100dB sensor gain is possible. With a collector transmit power of 0dBm and a sensor active gain of 100dB at 60GHz, a BER of 1E-3 at 1kbps is achievable at a range of Low Earth Orbit from collector to sensor.

VI. IMPLEMENTATION AND RESULTS

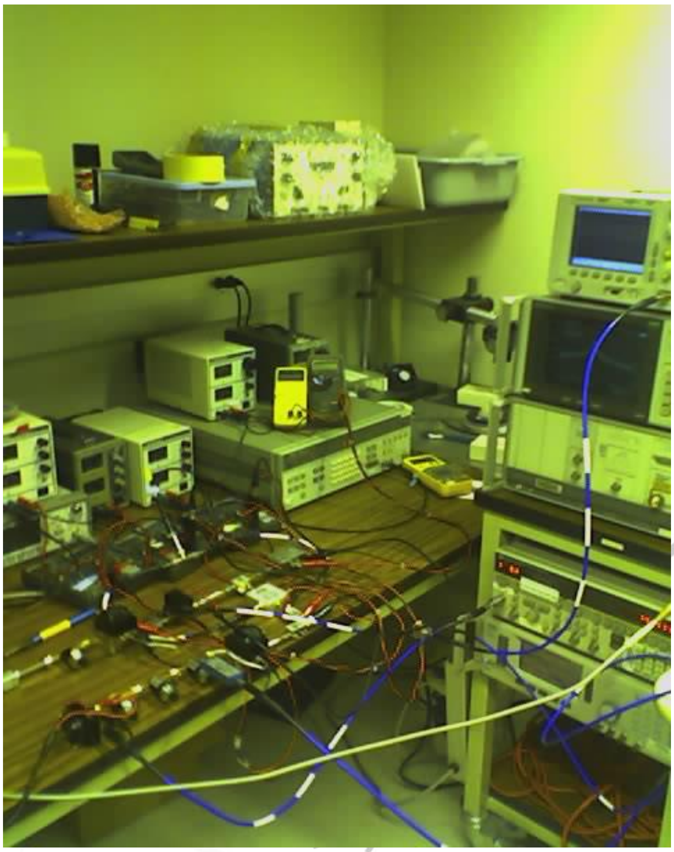

Figure 2: Active Sensor implementation using off the shelf brass board components. Output BPSK spectrum is visible on the spectrum analyzer.

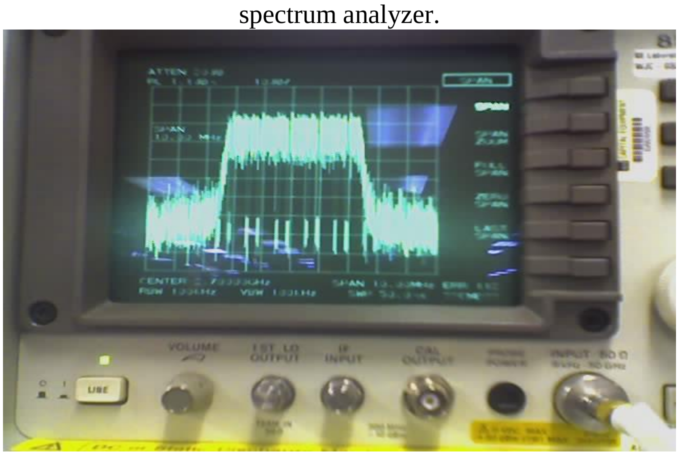

Figure 3: The Spectrum Analyzer shows the noise floor at the sensor output shaped by the filter and amlifier response. Half of the difference between pass band and stop band will give stable sensor gain. Absence of spurs indicates that the sensor is stable in this configuration.

REFERENCES

[1] MM-Wave Imaging Sensor Nets: A Scalable 60-GHz wireless sensor network, Munkyo Seo, Bharath Ananthasubramaniam, Mark Rodwell, and Upamanyu Madhow IEEE Microwave Symposium 2007
[2] Electronic Communications (Book) By Dennis Roddy and John Coolen