Imaging System Front-End at 202GHz Using LO/RF Isolation of Harmonic Mixer for Illumination

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Abstract: A millimeter-wave imaging system front-end at 202 GHz is developed and presented. To have more compact and economical transceiver and also due to the finite isolation between the LO and RF ports, a commercial harmonic mixer acts both as receiver and transmitter. To improve the performance as well as imaging quality an optomechanical system with ray optics designed configuration of mirrors is presented. Results of the 202 GHz imager for stand-off detection at 2.5m are illustrated.

1 INTRODUCTION

Active radio frequency imaging is utilized in two main applications; radar cross section (RCS) and concealed target objects detection. In RCS the wave reflectivity of desired target is considered, while in imaging applications of detection, the target objects are obscured by one or more barriers which are not transparent (Collins, *et al*. 1995). Active millimeter wave (mm-wave) imaging typically points to frequency range of 30GHz-300GHz (may also includes lower microwave frequencies (Collins, *et al*. 1995, Huguenin, *et al*. 1993, Sheen, *et al*. 2001, Sheen, *et al*. 2010)) is a topic of research interest due to facts that X-ray or other ionizing radiation imaging vehicles turns to be inconvenient, unsafe or ineffective in some practical situations.

Active mm-wave imaging systems are capable of penetrating common clothing and form an image of concealed targets like weapons (Appleby and Anderton, 2007) as well as a person's body. Moreover, relatively short wavelength of these systems, high resolution images can be achieved. Several commercial mm-wave imaging systems have been presented (TS4 and TS5 by Thruvision, Gen2 by Brijot). Recent effort lies in developing cost effective compact and robust systems to be used in the field of such as airports (García-Rial, *et al*. 2019).

Cold sky radiation is the main source of contrast for passive imagers at outdoor scenarios, make them useful to detect and image the thermal emission of the scene. Furthermore, the amount of attenuation for passive millimeter wave radiation in poor weather conditions like fog, snow, rain, dust is less than for visual or infrared radiation in orders of magnitude (Spinoulas, *et al*. 2012). However, at indoor environment, absence of cold sky radiation make imager to have higher sensitivity. This requirement renders passive imagers made for indoor scenarios to have lower imaging speed and higher overall cost.

One possible solution is to make use of active illumination of the scene in order to create radiometric contrast between objects of interest (Sheen, *et al*. 2010). Bryllert et al. have developed a transceiver module for a 3-D imaging radar at 220 GHz that consists of a frequency doubler which also acts as a subharminic mixer (SHM) based on GaAs semiconductor membrane technology (Bryllert, *et al*. 2013). Tang used infrared laser illumination along with a passive mm-wave imager in order to enlarge the radiometric contrast between different objects and background (Tang, 2016). Petkie et al. developed an imaging system at 640 GHz and concluded that active mm-wave imaging systems can have large dynamic ranges even with moderate illumination power compared to passive imaging (Petkie, *et al*. 2008).

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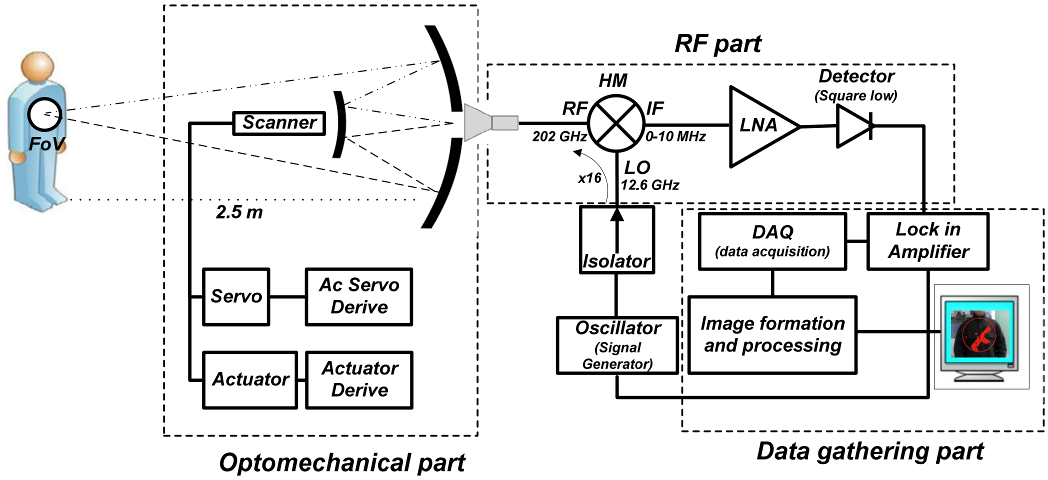


Figure 1: Block diagram of the implemented imager at 202GHz.

Canavero et al. have investigated most applicable/suitable type of illumination source for producing images with enhanced contrast and details for W band imaging systems at indoor environments (Canavero, *et al*. (2013). Finally, Grajal et al. have demonstrated a stand-off imaging system incorporating a compact front-end radar at 300 GHz in which a commercial-of-shelf (COTS) SHM is used as a transceiver (Grajal, *et al*. 2017).

In this paper active mm-wave imaging system at 202GHz with the use of COTS harmonic mixer for both illuminating the scene and receiving the reflected wave due to finite isolation between mixer's LO and RF ports is presented. Using mono-static power relation for desired configuration minimum required antenna gain is derived for given minimum detectable signal to noise ratio (SNR), noise equivalent power (NEP) of the receiver and selected harmonic mixer. To provide required radiation gain, a cassegrain antenna configuration with focusing point of the reflector system at 2.5m from front is implemented to improve the performance of the radiation of the horn antenna. A scanning system including a scanner and secondary inclinating and rotating mirror is used to spirally scan of the desired field of view (FoV). The main advantages of the proposed system are lower cost compared to conventional active imaging systems, simple hardware architecture and compactness due to integration of transmitter and receiver modules. To exclude very noise frequency noise like Flicker noise contribution, amplitude (AM) modulation of the LO signal is used. The results of the imaging show excellent performance of the presented mm-wave imager.

2 SYSTEM ARCHITECTURE AND ACTIVE MODE COMPUTATIONS

The mm-wave imager is a total power radiometer in 202 GHz frequency band. Block diagram of the mm-wave imager is shown in Figure 1 which consists of *RF part* including transceiver system, *optomechanical part* including cassegrain mirror and scanning system and finally *data gathering part* including data acquisition and image formation and processing.

In RF part, a scalar horn antenna with 10 dB gain at boresight direction is considered. Harmonic mixer of Radiometer Physics (RPG FS-Z220) is used which works in 16^{th} LO harmonic number with LO frequency 12.6 GHz and LO power of 15 dBm which is provided by Signal Generator HP8340. RF to IF conversion loss is 30dB and nearly 26dB isolation between LO/RF is measured and used in computations. Down converted signal at IF frequency amplified with the use of typical low noise amplifiers so that the signal power reaches detection limit of square low detector (HP 8474E). A function generator is used to AM modulate the signal deriving mixer’s LO port. A lock-in amplifier synchronized to the LO modulating signal to detect the down-converted signal buried in large background noise.

System noise temperature is given by

$$T_{sys} = T_{rec} + T_{A} \tag{1}$$

where T_{rec} and T_{A} are receiver and antenna noise equivalent temperature respectively. The antenna noise temperature is typically negligible compared to the receiver noise temperature. For T_{rec} we have

$$T_{rec} = T_M + L_M T_{IF} \tag{2}$$

where T_M is mixer noise temperature, L_M is RF to IF conversion loss factor and T_{IF} is LNA noise temperature.

Using overall system noise temperature, noise equivalent power (*NEP*) of the system at the specified bandwidth B (10 MHz is considered) is given by:

$$NEP = kT_{sys}B \tag{3}$$

where *k* is the Boltzmann constant. Typically, *m*LO to RF leakage in passive radiometer is regarded undesirable. In this work we make use of the *m*LO (*m*=16) to RF leakage as an additional means to the mm-wave imaging system to illuminate the scene and therefore configure an active mm-wave imager. The resulting active image can serve an additional information besides the primary passive image (García-Rial, *et al*. 2019, Grajal, *et al*. 2017). In this way, this setup represents a mono-static configuration in which a single antenna is used for both illuminating the scene and receiving the reflected waves. In order to get a detection criterion in active mode, utilizing mono-static radar equation and assuming that the receiver is able to detect only vertical polarization:

$$P_r = \frac{\varepsilon_{ap}^2 G_{\max}^2 \sigma^0 \lambda^2}{(4\pi)^3 R^4} P_t \tag{4}$$

where σ^0 is backscatter coefficient, $G_{\max}$ is the antenna gain boresight direction (neglecting sidelobes contributions), λ is free space wavelength, R is the distance of object and antenna and P_t is radiated power from the antenna and ε_{ap} is the efficiency of the antenna aperture (typical: 80%). By assuming P_{source} as derive power at LO port of mixer and $I_{mLO/RF}$ as isolation factor of LO/RF ports, we have $P_t = P_{source} I_{mLO/RF}$. Then the received power P_r should be satisfied inequality; $P_r \geq \Omega\, NEP$, where Ω is the minimum detectable SNR. Substituting from the equation derived above we have:

$$\frac{\varepsilon_{ap}^2 G_{\max}^2 \sigma^0 \lambda^2}{(4\pi)^3 R^4} P_{source} I_{mLO/RF} \geq \Omega\, kT_{sys}B \tag{5}$$

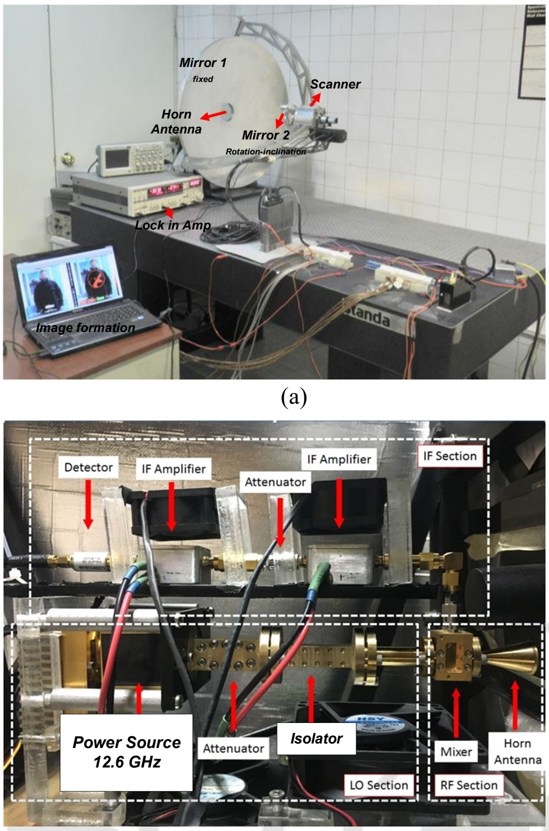
To help inequality (5) to be established one can make the right side of (5) as small as possible and the left side as large as possible. For selected harmonic mixer as well as other harmonic mixers, $P_{source} I_{mLO/RF}$ has its own certain amount and does not have much changes. Smaller T_{sys} required more sensitive and low noise receiver which directly increase the total cost of the system. But an efficient approach to have smaller minimum detectable SNR is AM modulating of the LO signal and making IF detector synchronized with it (Figure 1). Frequency of modulation can be chosen in [200KHz-800KHz] for $B = 10\text{MHz}$. Therefore very low frequency noise sources like Flicker noise would not contribute and make Ω smaller. In the left side of (5), it is focused on the $G_{\max}$. As illustrated in Figure 1 and 2, a cassegrain antenna configuration is used to redirect the incoming radiation from the scene into the horn. This configuration has a circular field of view (FoV) of 40cm in diameter focusing point of the reflector is set at a distance of 2.5m from the front panel. The location of the horn and the parameter of two reflecting mirrors, are designed using ray optics relations. The scanning of the FoV is performed via synchronized rotation and inclination of the secondary mirror which provides spiral scanning of the scene. It is proved that this configuration of optical mirrors with horn located in the aperture (Figure 2) makes the main lobe of radiation pattern of the horn more directive and conclusively improve $G_{\max}$.

3 RESULTS

Figure 3 shows indoor experimental results of the implemented mm-wave imaging system at 202 GHz. They show someone standing at 2.5m in front of the system with concealed metallic gun simulator and pierced plate which their images are appropriately formed and perfect detection is done with the use of active illumination of power leakage LO/RF of the mixer.

4 CONCLUSION

In this paper, with the use of finite isolation between mixer's LO and RF ports for illuminating the scene, active mm-wave imaging system at 202GHz is presented. An optomechanical system with ray optics designed configuration of mirrors is also presented. Stand-off imaging of the target in 2.5m



(a)

(b)

Figure 2: (a) Front and (b) behind view of the imager.

Figure 3: Results of imaging at 202 GHz with proposed imager, metallic gun simulator and metallic pierced plate.

is implemented with scanning system including a scanner and inclinating/rotating mirror. Such a configuration of mirrors improve the gain of the horn antenna located on the aperture of the system due to dual reflection mechanism to satisfy the mono-static radar equation required for detection. The results of the imaging show excellent performance of the presented mm-wave imager.

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