# Investigations on Millimeter Wave Detection of Power Lines from a Safe Distance

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## Abstract

**A millimeter wave obstacle detection system for helicopters is installed to observe the feasibility for the detection of power lines from a safe distance, using 77 and 94 GHz central frequencies, separately. A two wire power line system is illuminated using two different antennas with 24 and 27 $dB_i$ gains, comparatively. An external W band (92-96 GHz) power amplifier is also used to measure power line response for increasing the maximum detection distance. It's shown that the use of 77 GHz central frequency, as well as higher antenna gain and output power, is better in terms of increasing the detection range of the millimeter wave radar system. The feasibility measurements are also validated using the theoretical radar formula. A collision avoidance and warning system to detect power lines is also discussed using a compact millimeter wave radar module for the future study.**

## 1. Introduction

Helicopters usually face and collide with obstacles like power lines while flying at low altitudes under fair wheather conditions such as foggy, cloudy or rainy wheather. Even in good weather conditions, they are very difficult to see for pilots because they are easily hidden by the landscape [1]. There are various radar systems developed to detect the existence and distance of the obstacles [1-3].

A FM-CW 94 GHz millimeter-wave radar sensor system has been developed with high gain folded reflect-array antennas, in Japan [1]. The maximum range has been obtained as 800 m, in that study. In [2], a compact 76 GHz radar with direct conversion method for helicopter collision avoidance systems has been developed with additional support of color camera and infrared camera. A power line detection for millimeter-wave radar video has been done by the use of Hough transform in radar videos [3]. A global system achieving an image fusion between a CCD, an infrared camera and a 94 GHz mm-wave FM-CW radar has been developed [4-6] for civil helicopters. Another research conducted at the ENRI [7-8] has shown the benefit of having a fine resolution IR camera for the detection of thin obstacles.

The active millimeter-wave (mmW) frequency is in the range from 30 to 300 GHz, corresponding to the wavelength from 1 cm to 1 mm, but the imaging or detection systems need to operate at a frequency near an atmospheric window where the absorption due to water vapor is minimum [3]. These windows are centered around 35, 94, 140, and 220 GHz, etc. In this study, both 94 GHz and 77 GHz central frequencies, which are mainly used for obstacle detection system for helicopters, is studied to observe the differences in terms of system performance.

A short description of the millimeter wave radar measurement system will be given in the second section. Third section deals with the measurement results with some theoretical validations. Finally, a 94 GHz FMCW will be discussed for the future study.

## 2. Millimeter Wave Obstacle Detection System

The measurement setup consists of four major parts Agilent PNA Network Analyzer (VNA) E8362B, two WR10 T/R millimeter wave extender modules and N5260A extender controller. Since the upper limit of the VNA is 20 GHz, the 67 to 110 GHz extender modules are attached to the VNA using the controller to measure power line responses at millimeter wave frequencies. A WR10 T/R millimeter wave extender module contains multipliers (x6) that extends 11.167 to 18.333 GHz RF input signal to 67 to 110 GHz frequency range and test IF and reference IF signals for VNA are obtained by using downconversion mixers before transmitting. After passing through the channel, the received signal is downconverted at the receiver module by using downconversion mixers and the resulting test IF (<300 MHz) is fed back to the VNA. Difference in the transmitted and received signal is analyzed to find channel characteristics. The corresponding block diagram of our setup is shown in Fig. 1.

The 67 to 110 GHz millimeter wave modules includes balanced multipliers, which is driven by an extended band WR-10 multiplier chain with the WR-10 waveguide output interface. The RF drive signal may be either CW or swept frequency. The required RF or LO signal power to operate the modules is +6 dBm. The dynamic range is typically 89 dB and the WR10 waveguide output power of the millimeter wave T/R is around -5 dBm.

In this study, 76.5 to 77.5 GHz and 93.5 to 94.4 GHz frequency bands are specially used to get better back scattering responses from the power lines, because of low atmospheric losses at those central frequencies. Back scattering response is acquired by recording forward scattering parameter ($S_{21}$) using the measurement setup shown in Fig. 1. All of measurements are taken with standard rectangular horn antenna, with the gain of 24 $dB_i$ and circular horn antenna with the gain of 27 $dB_i$, respectively, as shown in Table 1, attached at both the transmitter and the receiver. Full 1 GHz band measurements are recorded with 801 points and 700 Hz IFBW. Then, these frequency domain data are converted to range profile using IFFT. These parameters significantly improve noise floor and dynamic range of the millimeter wave measurement system.

**Fig. 1.** Millimeter wave measurement system.

Another measurement system is equipped with an additional external power amplifier (Quinstar) operating between 92 GHz and 96 GHz with the output power of +30 dBm and gain of 42 dB, as shown in Fig. 2. This system will be used to observe the feasibility or need of the power amplifier with WR10 standard to increase the measurement range at the central frequency of 94 GHz.

**Fig. 2.** 92 - 96 GHz power amplifier (Quinstar).

The antennas used in the measurement system are made by Elmika, and the details of their parameters are given in Table 1. In each case, both transmit and receive antennas are used as same.

**Table 1.** Antenna parameters.

| **Parameter:** | **Rectangular Horn Antenna**  | **Circular Horn antenna**  |
|---|---|---|
| Typical VSWR (75GHz-110GHz) | 1.15 | 1.1 |
| Gain (dB$_i$) | 24 | 27.5 |
| HPBW in E-plane | 10° | 6° |
| HPBW in H-plane | 12° | 6° |

## 3. Measurement Results

The incidence angle of the incoming electromagnetic waves with respect to the alignment of the power lines significantly influence on the signature of the power line for the radar systems [9-10]. In this study, preliminary measurements are carried out to measure radar cross section (RCS) of a two wire power line system (Fig. 1). For this purpose, our measurement system is calibrated using a triangular corner reflector with L= 17 cm, for both 77 GHz and 94 GHz frequencies (Fig. 3). The radar cross section formula for the triangular corner reflectors are also given in Eq. 1.

$$\sigma_{reflector} = \frac{4\pi L^4}{3\lambda^2} \qquad (1)$$

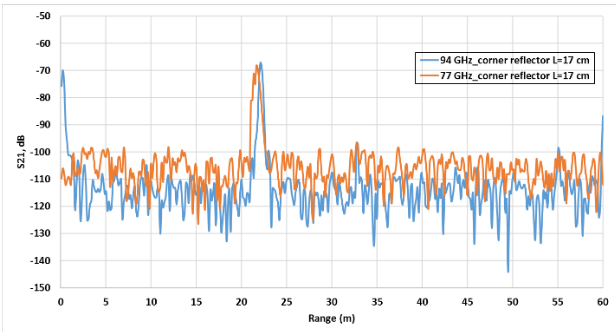



**Fig. 3.** Range profile for the corner reflector with L=17 cm.

The measurements of the power lines are done by perpendicular incidence angle with respect to the alignment of the power lines, as shown in Fig. 1. According to the measured range profile results in Fig. 4, there exists two peaks, around 19.7 m and 22 m, which shows the location of the two wires separated by approximately 2 m. By using the calibration results in Fig. 3, the

RCS of the measured two wire line system is computed approximately as 1.72 dBsm for 77 GHz and 1.96 dBsm for 94 GHz, which is coinsiding RCS values given in literature [9-10]. Those values can be used as the radar system design parameters.

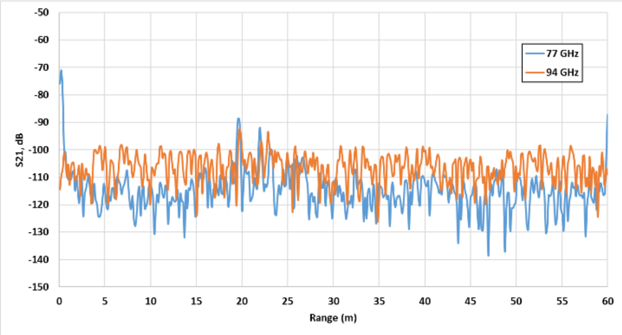
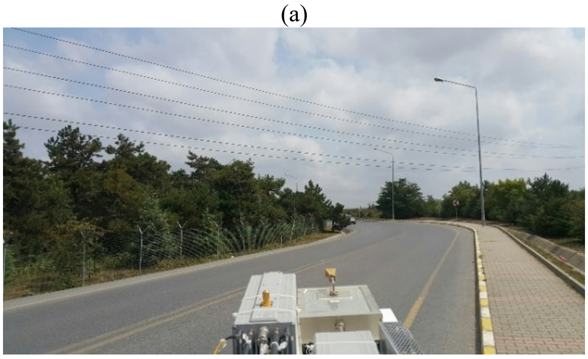



**Fig. 4.** Range profile for the power line.

According to the results in Fig. 4, the power lines are more easily observed on the range profile for 77 GHz since free space loss is obviously less. In the following measurement, the two wire power line system is illuminated with oblique incidence angle by using two different antennas with 24 and 27.5 dBi gains (Table 1), comparatively. Since no peaks are obtained in the range profile in the first trials for the oblique incidence, therefore the power amplifier, in Fig. 2, is used in this comparative measurement study at 94 GHz, as shown in Fig. 5.

(a)



(b)

**Fig. 5.** Millimeter wave measurement system with power amplifier and (a) 27.5 dBi and (b) 24 dBi antennas.

According to the results in Fig. 6, the power line system distance is measured at around 37 m centered and the difference of the S21 response between two different antennas is around 7 dB, which is successfully equal to the two times of the gain differences.

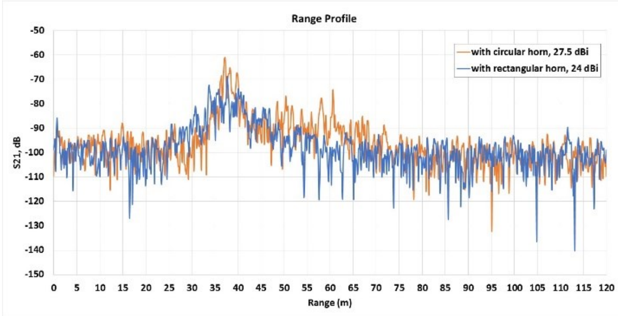



**Fig. 6.** Range profile for the power line for different antenna gains.

In the final measurements, another two wire power line system with two long street light poles is illuminated using the same measurement system at 94 GHz with and without power amplifier, as shown in Fig. 7., comparatively. According to the measured range profile results in Fig. 8, by the aid of power amplifier, three peaks are clearly emerged, around 38.4 m, 49.4 m and 60.8 m, which shows the location of the first long street light pole, the power line system and the second farther long street light pole, respectively. According to the measurements done in over all, our system with 27.5 dBi antennas have maximum detection range for the power lines, up to 100 m.

**Fig. 7.** Millimeter wave measurement system with power amplifier and 24 dBi antenna.

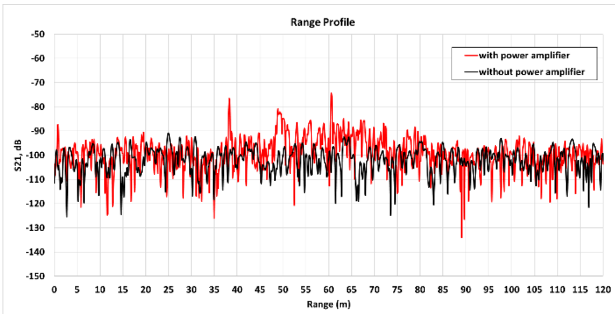



**Fig. 8.** Range profile for the power line obtained with and without power amplifier.

One can easily compute the system validation and requirements using the classical radar formula given as follows:

$$\sigma = \frac{P_r (4\pi)^3 R^4}{P_t G_t G_r \lambda^2} \quad (2)$$

The computed results obtained in Fig. 9 validates our measurement results obtained with antennas with the gain under 30 dBi. One should use higher gain antennas (up to 47-48 dBi) to increase the detection range up to at most 1 km. In this calculations, transmit power is used as +30 dBm, SNR as 10 dB and dynamic range as around 105 dB. If one only uses solid state power amplifier technology, the upper limit of the output power is around +30 dBm. Therefore, increasing the antenna gain would be the most critical parameters to increase the detection range of the power lines.

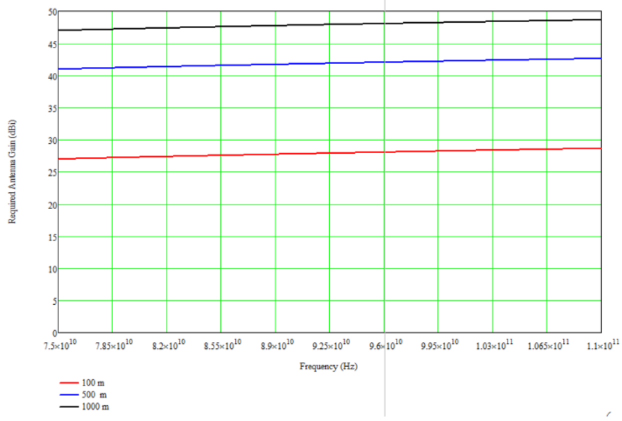
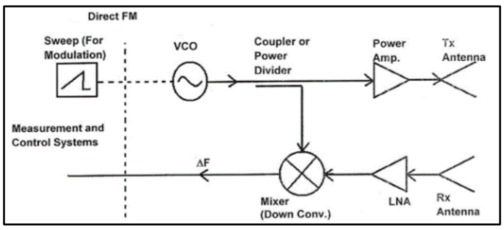
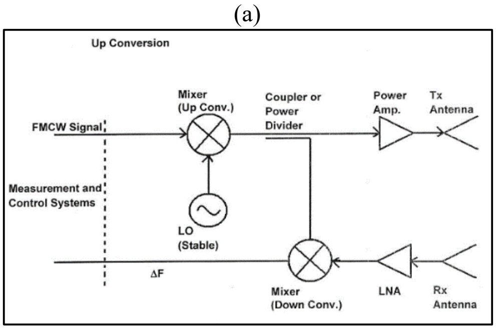



**Fig. 9.** Required antenna gain for different detection ranges.

Our next mission will be to recover the system from the experimental measurement setup, in Fig. 1, in the future. Therefore, in the future study, a compact 94 GHz FMCW millimeter wave radar system is planned to developed, as shown in Fig. 10. For the radar architecture in Fig. 10 (a), a synthesized low frequency FMCW signal (i.e. 9.4 GHz) is applied to a multiplier (i.e. x10) before coupler. In comparison, in Fig. 10 (b), a synthesized lower frequency FMCW signal (i.e. 1.5 GHz) is applied to a mixer by the use of a local oscillator (i.e. 93 GHz).




(a)




(b)

**Fig. 10.** Two different 94 GHz FMCW radar architecture schematics.

The system in Fig. 10 (a) seems to be more applicable because of the stability, availability and usage requirement of the millimeter wave local oscillator in Fig. 10 (b).

## 4. Conclusions

The feasibility analysis for an experimental millimeter wave power line detection system for helicopters has been done by using 77 and 94 GHz central frequencies. It's shown that the use of 77 GHz central frequency, as well as higher antenna gain and output power, is better in terms of increasing the detection range of the radar system. The feasibility measurements are also validated using the theoretical radar formula. Moreover, a compact 94 GHz FMCW millimeter wave radar system is planned to developed using two different radar architectures discussed in the paper.

## 5. Acknowledgements

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## 6. References

[1] C. Migliaccio, B. D. Nguyen, Ch. Pichot, N. Yonemoto, K. Yamamoto, K. Yamada, H. Nasui, W. Mayer, A. Gronau, W. Menzel, "Millimeter-wave radar for rescue helicopters", in *9th International Conference on Control Automation Robotics & Vision (*ICARCV 2006*)*, Singapore, 2006, pp. *1-6.*

[2] C. Migliaccio, B. D. Nguyen, Ch. Pichot, N. Yonemoto, K. Yamamoto, K. Yamada, H. Nasui, W. Mayer, A. Gronau, W. Menzel, "76 GHz millimeter-wave radar system for helicopter obstacle detection", in *2011 Proceedings International Radar Symposium (IRS)*, Leipzig, Germany, 2011, pp. *1-6.*

[3] Qirong Ma, "Power line detection for millimeter-wave radar video", Ph.D. thesis, Dept. of Electrical Engineering, Univ. of Washington, Washington D.C., 2012.

[4] N. Yonemoto, K. Yamamoto, et al., "Obstacle Detection and Warning for Helicopter Flight by Infrared and Millimeter Wave," *Proceedings of SPIE*, Vol. 5081, pp.31-38, 2003.

[5] N. Yonemoto K. Yamamoto, et al., "A new color, IR, and radar data fusion for obstacle detection and collision warning," *Proceedings of SPIE*, vol. 5424, pp.31-38, 2004.

[6] K. Yamamoto, N. Yonemoto, et al., "The Performance of Airborne 94 GHz Radar for Obstacle Detection," Proceedings of IRS 2005, pp.147-152, 2005.

[7] K. Yamamoto, and K. Yamada, "Image processing and fusion to detect navigation obstacles," *SPIE Proceedings*, vol. 3374, pp.337-346, 1998

[8] K. Yamamoto and K. Yamada, "Obstacle detection for helicopters flights by infrared images", *Proceedings of SPIE*, Vol. 4363, 2001.

[9] J. K. Author, "On the scattering mechanism of power lines at millimeter-waves", *IEEE Transactions on Geoscience and Remote Sensing*, vol. *40,* no. *9,* pp. *1895-1903,* Sep, 2002.

[10] Wei Huang, Xiaoliang Yang, Qingchun Wei, "The detection model analysis for power lines at millimeter-waves", in *5th Global Symposium on Millimeter Waves (GSMM)*, Harbin, China, 2012, pp. *541-544.*