Characterizing an S-band Marine Radar Receiver in the Presence of Interference

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***Abstract*—Characterizing the effects that out-of-band interference has on the performance of an S-band marine radar receiver's IF output normally requires non-linear network analysis.**

We have developed a non-linear network analyzer from commonly available laboratory instruments. Our automated system operates over a broad range of interferer frequencies and power levels. It enables the collection of the data required for an extensive analysis of a radar receiver's AM-AM and AM-PM performance in the presence of interference. With this data, engineers can begin to make recommendations on protecting these radars from potential interference.

I. Introduction

Receivers that use low-noise front ends (LNFEs) are susceptible to interference from out-of-band (OoB) signals [1]–[3]. Spectrum reallocation to accommodate the growing spectrum needs of broadband radio service systems (such as WiMAX and LTE) can potentially increase the probability of this interference to S-band marine radars.

The impact of the interference can be analyzed with knowledge of the receiver's amplitude-to-amplitude (AM-AM) and amplitude-to-phase (AM-PM) characteristics [4]. AM-AM characteristics describe a system's output power over a range of input power levels, and AM-PM characteristics describe a system's output phase over a range of input power levels.

Acquiring AM-AM and AM-PM characteristics is usually accomplished with a network analyzer. Because our receiver has different input and output frequencies (i.e., radio frequency (RF) input and intermediate frequency (IF) output), a *non-linear* network analyzer is needed. A non-linear network analyzer can measure a device's output power and phase as a function of input power *and* input frequency. Non-linear network analyzers are very specialized and expensive instruments; many engineers do not have access to one. This paper describes how we built one from commonly available laboratory instruments. We also describe our calibration method, which accounts for insertion loss and insertion phase in both the RF and IF chain of the receiver.

II. Measurement Scenario

The radar components of interest are the circulator, limiter, and LNFE. These components are the first in the radar receiver signal processing chain. A photograph of these components is shown in Fig. 1. Note that the LNFE in this system was modified to allow a local oscillator (LO) input for frequency stability.

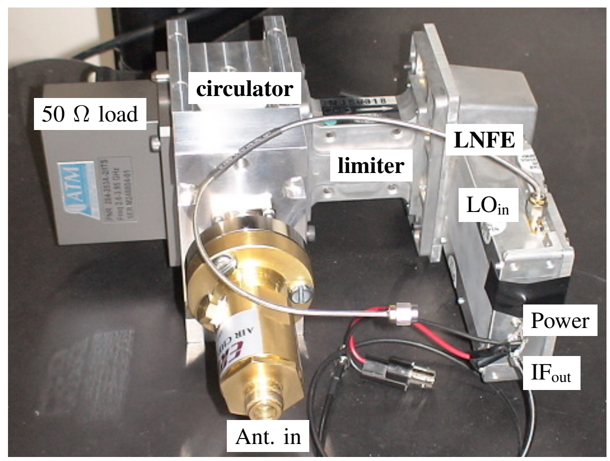

Fig. 1: Photograph of S-band marine radar receiver

S-band marine radars operate at 3050 MHz, and the IF output is at 60 MHz. We are interested in the effects of OoB signals of varying frequencies and power levels. The frequencies of interest occur in two ranges (above and below 3050 MHz):

- 2850 MHz through 3000 MHz (lower range)
- 3100 MHz through 3250 MHz (upper range)

We chose to examine these ranges in 50 MHz increments, yielding eight OoB frequencies where we will collect data:

1) 2850
2) 2900
3) 2950
4) 3000
5) 3100
6) 3150
7) 3200
8) 3250

These frequencies were chosen because they are passed by the radar system's limiter with minimal attenuation.

The power levels of interest range from −50 to +20 dBm, in 5 dB increments, yielding a total of 15 power levels. These

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levels were chosen because they span the ranges of potential WiMAX and LTE signal powers.

This results in a total of 120 measurements which will be used to characterize the AM-AM and AM-PM conversions.

III. Measurement System

The measurement system consists of:

- A vector signal generator (VSG) as the OoB signal source
- A vector signal analyzer (VSA) to record the receiver's IF output
- A signal generator to drive the LNFE's LO
- A rubidium clock for synchronization
- Open source software, which controls the VSA's GUI

The VSG provides the RF input signals, and the VSA records the receiver's IF output; the rubidium clock provides a common timing reference; a Windows® computer runs the open source software AutoHotkey[1] [5] which controls the VSA's GUI and allows for the automated collection of the data. A photograph of this system is shown in Fig. 2.

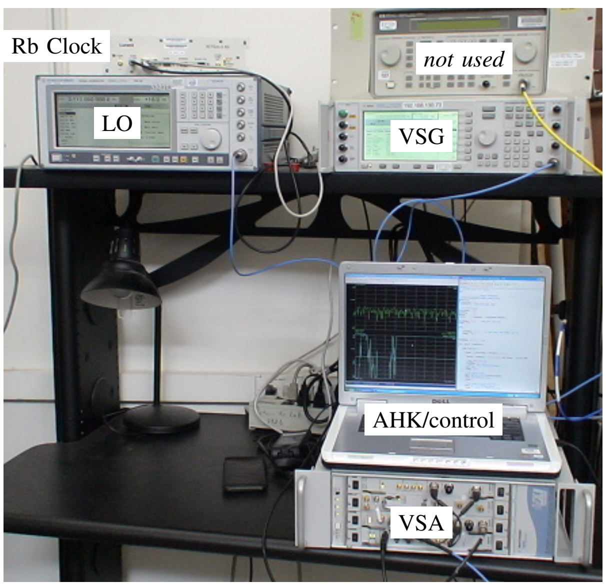

Fig. 2: Photograph of measurement system, showing rubidium clock, LO, VSG, computer (running VSA GUI and AutoHotkey) and VSA

A block diagram of the measurement system is shown in Fig. 3. The RF signal is fed from the VSG to the antenna port of the circulator. The receive port of the circulator feeds into the radar's limiter, and then into the LNFE. The transmit port of the circulator is terminated with a 50 Ω load. The output of the LNFE is filtered by a 20 MHz wide band pass filter (BPF) centered at 60 MHz, and then recorded by the VSA. The LNFE's LO, along with the VSG and VSA, are referenced to the rubidium clock.

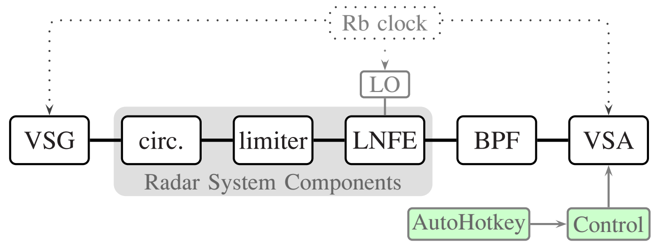

Fig. 3: Block diagram of measurement system

The VSG is programmed to dwell on each power level and frequency while the VSA records the radar system's 60 MHz I-Q output. After a few seconds have elapsed, the VSG switches to the next power level and frequency, and the VSA acquires the next recording.

The VSA's GUI is controlled by AutoHotkey. AutoHotkey was programmed to send the appropriate keystrokes to the VSA's GUI to have the VSA:

1) Acquire data from hardware
2) "Restart" the measurement
3) Start the recording
4) Save the recording on disk with an appropriate filename after the recording finishes

Each of these steps is necessary to acquire one recording. These steps are repeated until all of the data are acquired.

Using AutoHotkey, the 120 VSA recordings can be acquired automatically in about 50 minutes. Doing this task manually would be too time-consuming. AutoHotkey was chosen to control the VSA because of its simplicity and low development time.

IV. Calibration Technique

The calibration technique consists of two parts: the collection of raw data and a software/mathematical correction. These parts are described in Sections IV-A and IV-B, respectively.

A. Collection of Raw Data

The raw data are collected in three sets of measurements, each with its own measurement system:

1) Baseline measurement (Fig. 4)
2) RF segment calibration measurement (Fig. 5)
3) IF segment calibration measurement (Fig. 6)

These measurement sets, and their respective measurement systems, are described below.

1) Baseline Measurement: The baseline measurement system is shown in Fig. 4. It measures from the output of the signal generator, through the radar system components, to the input of the signal analyzer. It consists of the signal generator, an RF cable, the radar system components (circulator, limiter, and LNFE), an IF cable, an IF band-pass filter, another IF cable, the signal analyzer, and the rubidium clock. The RF segment is shown in dotted red, and the IF segment is shown

[1]Certain commercial equipment and materials are identified in this article to specify adequately the technical aspects of the reported results. In no case does such identification imply recommendation or endorsement by the National Telecommunications and Information Administration, nor does it imply that the material or equipment identified is the best available for this purpose.

in dashed blue. A total of 120 recordings are acquired at this step.

The data collected in this step will be calibrated later with the data collected in steps two and three.

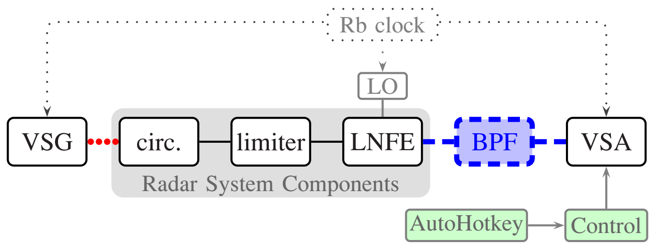

Fig. 4: Baseline measurement system, showing RF segment (2850-3250 MHz) in dotted red and IF segment (60 MHz) in dashed blue

2) RF Segment Measurement: The RF measurement system is shown in Fig. 5. It measures from the output of the signal generator to the input to the radar system components. It consists of a signal generator, an RF cable, the signal analyzer, and the rubidium clock. This system measures RF frequencies between 2850 and 3250 MHz. A total of 120 recordings are acquired at this step.

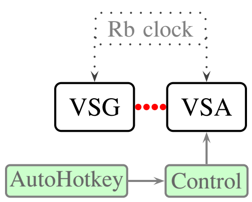

Fig. 5: Block diagram of RF measurement system (2850-3250 MHz)

3) IF Segment Measurement: The IF measurement system is shown in Fig. 6. It measures the IF chain from the output of the radar to the input of the signal analyzer. The IF measurement system consists of a signal generator, an IF cable, the IF BPF, another IF cable, the signal analyzer, and the rubidium clock. A total of 15 recordings are acquired at this step.

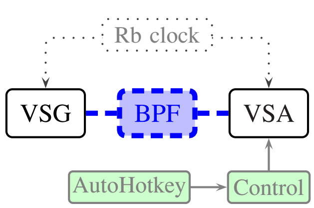

Fig. 6: Block diagram of IF measurement system (60 MHz)

Note that the BPF is included in the IF calibration for purposes of demonstrating the flexibility of this measurement system. This BPF could be any network component whose effect we wish to calibrate out of a measurement. The BPF could have been considered a part of the radar system, in which case the IF segment measurement would consist of measuring the IF cable only.

B. *Software/Mathematical Correction*

The software/mathematical correction takes the RF and IF calibration measurement data sets (acquired in steps two and three) and applies them to the baseline measurement data set (collected in step one) to create a calibrated measurement set. P_{in} is measured at the input to the circulator, and P_{out} is measured at the output of the LNFE.

The calibrated input power at each frequency and power level, $\hat{P}_{in_{f,P}}$, is computed by subtracting the RF insertion loss at each frequency and power level ($IL_{RF_{f,P}}$) from the baseline measurement's input power at each frequency and power level ($\dot{P}_{in_{f,P}}$). This yields the calibrated input power at each frequency and power level, $\hat{P}_{in_{f,P}}$. This is described by (1).

$$\hat{P}_{in_{f,P}} = \dot{P}_{in_{f,P}} - IL_{RF_{f,P}} \tag{1}$$

The calibrated output power at each frequency and power level, $\hat{P}_{out_{f,P}}$, is computed by adding the IF insertion loss at each frequency and power level ($IL_{IF_{f,P}}$) to the baseline measurement's output power at each frequency and power level ($\dot{P}_{out_{f,P}}$). This is described by (2).

$$\hat{P}_{out_{f,P}} = \dot{P}_{out_{f,P}} + IL_{IF_{f,P}} \tag{2}$$

The calibrated output phase at each frequency and power level, $\hat{\Phi}_{f,P}$, is computed by subtracting the RF and IF insertion phases at each frequency and power level ($\alpha_{f,P}$ and $\beta_{f,P}$) from the baseline measurement's output phase at each frequency and power level ($\dot{\Phi}_{f,P}$). This is described by (3).

$$\hat{\dot{\Phi}}_{f,P} = \dot{\Phi}_{f,P} - (\alpha_{f,P} + \beta_{f,P}) \tag{3}$$

V. RESULTS

The IF and RF insertion losses, $IL_{IF_{f,P}}$ and $IL_{RF_{f,P}}$, acquired from the calibration measurements are shown in Fig. 7. The IF and RF insertion phases, $\alpha_{f,P}$ and $\beta_{f,P}$, acquired from the calibration measurements are shown in Fig. 8.

The calibrated and uncalibrated AM-AM conversions are shown in Fig. 9. For the calibrated curves (solid lines), the x-axis corresponds to $\hat{P}_{in}$, and the y-axis corresponds to $\hat{P}_{out}$. For the uncalibrated curves (dashed lines), the x-axis corresponds to $\dot{P}_{in}$, and the y-axis corresponds to $\dot{P}_{out}$.

The calibrated and uncalibrated AM-PM conversions are shown in Fig. 10. For the calibrated curves (solid lines), the x-axis corresponds to $\hat{P}_{in}$, and the y-axis corresponds to $\hat{\Phi}$. For the uncalibrated curves (dashed lines), the x-axis corresponds to $\dot{P}_{in}$, and the y-axis corresponds to $\dot{\Phi}$.

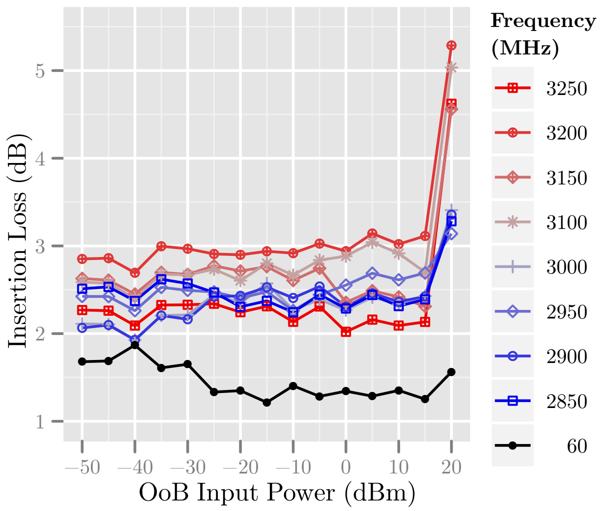

Fig. 7: RF and IF insertion losses

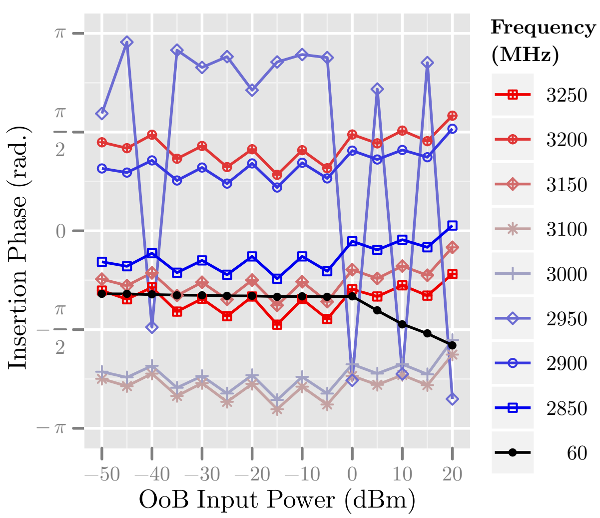

Fig. 8: RF and IF insertion phases

VI. Conclusion

Our measurement system and calibration technique can automatically acquire the data needed to characterize the effect of interference on the IF output of an S-band marine radar receiver. With this data, engineers can begin to make recommendations on protecting these radars from potential interference.

Our system measured and calibrated the RF and IF insertion losses and phases from the AM-AM and AM-PM baseline measurements to produce the calibrated measurements. It also shows how insertion loss and phase loss vary with frequency and power.

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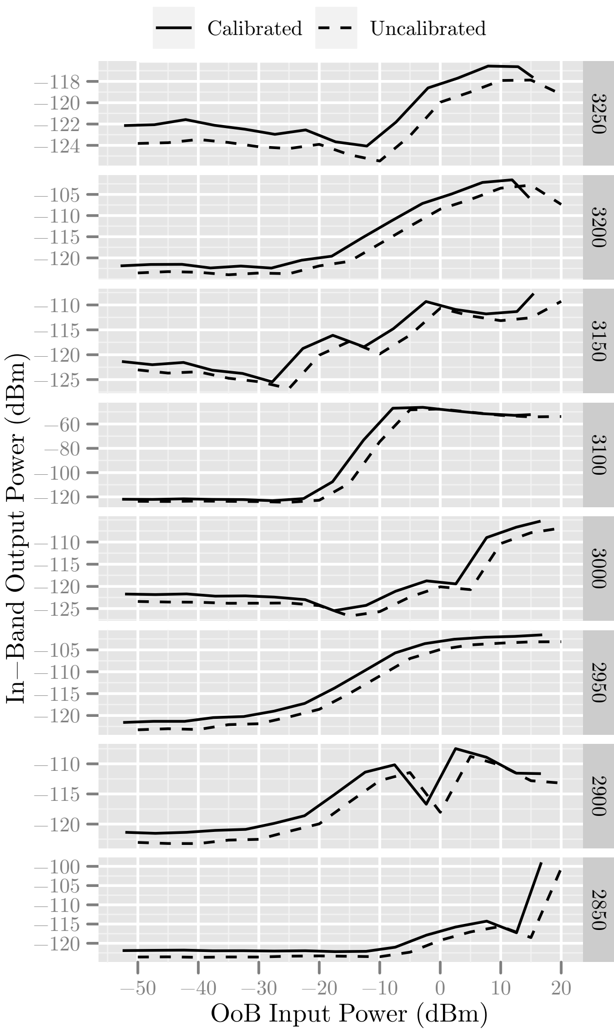

Fig. 9: Calibrated (solid) and uncalibrated (dashed) AM-AM conversions for each frequency

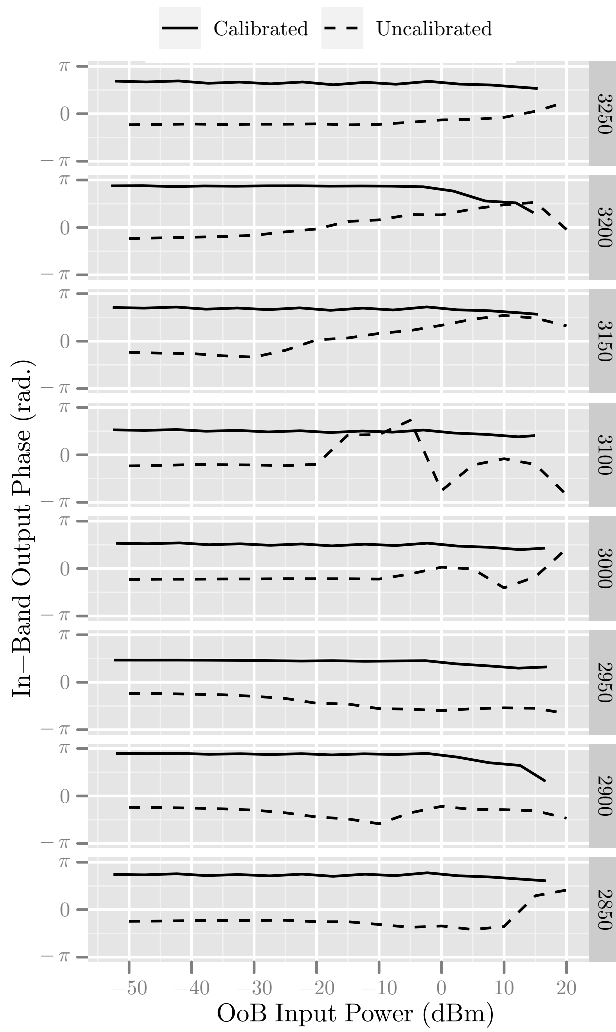

Fig. 10: Calibrated (solid) and uncalibrated (dashed) AM-PM conversions for each frequency