A Simple Measurement Technique for Characterizing Active Antennas

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Abstract — Testing active antennas or polarimetric radar calibrators in the far-field (plane wave excitation) is complicated by imperfect isolation between transmitting and receiving channels. We describe a far-field reflectometry setup which overcomes this problem. A large dynamic range is achieved by modulating the active element bias and using a quadrature receiver and lock-in detection scheme. Measured results compare favorably with other existing techniques.

I. INTRODUCTION

To overcome the problems of limited power-handling capacity of millimeter-wave semiconductor devices and lossy waveguiding structures, power combining with active antenna arrays have been proposed. Recent research efforts with such arrays have focused on beam amplifiers, and several different topologies for array cells and grid amplifiers have been reported [1]-[6]. The amplifier cells generally consist of two antennas, coupling energy to and from a high-frequency amplifier circuit, with input/output isolation achieved through the use of orthogonal polarization of the antennas. A simple far-field technique has recently been described which is suitable for transmission amplifiers [1]-[3]. This technique uses two standard waveguide horn antennas to measure the power transmission through the amplifier cell, with a simple calibration that relies on the Friis transmission equation [7]. We describe a qualitatively similar technique in this paper that is suitable for reflection amplifiers. This measurement is somewhat more complicated than the transmission measurement due to imperfect isolation between the transmitting and receiving antennas. The resulting technique is suitable for the characterization of active radar calibrators [8].

II. MEASUREMENT TECHNIQUE AND SYSTEM CALIBRATION

An typical active antenna cell is shown in the inset of Figure 1a. Two identical planar antennas with a gain (directivity) of G_{ant} are coupled to an amplifier circuit with a power gain of G_{amp}. The goal of the measurement is to determine the reflection gain ($G_{\text{ant}}^2 G_{\text{amp}}$) vs. frequency of the active antenna for different combinations of transmitted and received signal polarizations. A simple system for such measurements is also shown in Figure 1a, consisting of a CW transmitter section and a homodyne receiver using a quadrature mixer for detection. Several practical difficulties are encountered in this system such as the imperfect isolation beetween the transmitter and receivier, the DC offset arising from the diode mismatch in the mixer, and the non-ideal 90° phase shift between I and Q channels of the quadrature mixer.

All of these problems can be solved using the measurement setup shown in Figure 1b and a mixer correction algorithm [9]. The transmitter/receiver components are essentially the same as shown in Figure 1. To distinguish the desired signal from the crosstalk between antennas, the active antenna is bias-modulated (switched on and off) at a periodic rate set by a function generator (which is buffered by a simple relay circuit). Dual-phase lock-in amplifiers are then used to sample the mixer IF outputs, and should record only the modulated signal arriving at the receiver from the AUT. Here we assume that there is no transmission through the amplifier with DC bias off since the signal is negligible compared to that with bias on for amplifiers. Letting V_{on} and V_{off} denote the IF voltages measured when the device is on and off, then with reference to Figure 1b we have

$$\begin{aligned} V_{\text{on}} &= V_{\text{DC}} + kV_A \cos\Phi_a + kV_B \cos\Phi_b \\ V_{\text{off}} &= V_{\text{DC}} + kV_A \cos\Phi_a \end{aligned} \tag{1}$$

where k is the proportionality constant between IF output and the RF input; Φ_a and Φ_b are the phases of the received crosstalk and desired signals with respect to the transmitted signal, respectively. Note the DC offset voltage does not change appreciably since it is primarily a function of the LO drive power. The lock-in amplifier will record a signal proportional to the difference,

$$\Delta V = V_{\text{on}} - V_{\text{off}} = kV_B \cos\Phi_b \tag{2}$$

Hence both the unwanted crosstalk signal and the DC offset are eliminated. Once the proportionality constant k is known, the amplitude and phase of the received signal are determined by making use of both quadrature IF outputs, which give

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$$\begin{aligned}\Delta V_I &= kV_B \cos \Phi_b \\ \Delta V_Q &= kV_B \sin \Phi_b\end{aligned} \tag{3}$$

The next step is to determine the relationship between the actual receiving power and the signal detected by the lock-in amplifier. This can be done with a simple calibration step. The AUT is replaced by a standard gain horn with the correct polarization. A measurable amount of power is coupled from the sweeper into the standard gain horn, and modulated by a PIN diode switching circuit at the same modulation frequency, f_m. Using similar arguments as above, the signal measured by the lock-in will be given by

$$\Delta V = kV_C \cos \Phi_c \tag{4}$$

where V_C and Φ_c are the amplitude and phase of the known calibration signal. Note that the transmitting horn still sends out a signal during calibration in order to maintain similar conditions to the actual measurement. This insures that the proportionality constant k will be the same in both (3) and (4). This method essentially calibrated the AUT to a standard gain horn.

Using these two measurements, along with the fact that the received power is proportional to the square of the voltage measured by lock-in, the gain of the amplifier can be determined by the following equation,

$$G_{\text{ant}}^2 G_{\text{amp}} = \left[\frac{V_B}{V_C}\right]^2 \frac{P_{\text{cal}}}{P_{\text{tran}}} \left[\frac{4\pi R}{\lambda}\right]^2 \frac{G_{\text{cal}}}{G_t} \tag{5}$$

where V_B and V_C are the voltages recorded by lock-in during calibration and actual measurement, respectively; P_{cali} is the measured calibration power fed into the standard gain horn and P_{tran} is the power delivered to the transmitting antenna; R is the distance, λ is the wavelength; G_t and G_{cal} are the gains of the receiving horn and the horn used in calibration. Unless the gain of the antennas on the AUT is known, it is impossible to determine actual amplifier gain, G_{amp}. This collection of terms can be called the Effective Isotropic Power Gain (EIPG) of the active antenna cell.

III. RESULTS

Typical I&Q data (ΔV_I and ΔV_Q) measured versus frequency for a narrowband active antenna are shown in Figure 5a. From this data it is necessary to calculate the amplitude of the signal, V_B, to insert in the equation (4) for gain. If the I and Q channels are in perfect phase quadrature and have perfect amplitude balance, then the magnitude of the signal is given by

$$kV_B = \sqrt{\Delta V_I^2 + \Delta V_Q^2} \tag{6}$$

The result is shown in Figure 2a. Note those ripples imply that the phase shift is not exactly 90° and/or there is an amplitude imbalance on the IF channals. Under certain condition, both problems can be solved by a mixer correction algorithm [9] and the corrected curve is shown in Figure 2b, where the high-frequency ripples have clearly been reduced. The measured gain curve of this amplifier is shown in Figure 3a, where a patch antenna gain of $G_{\text{ant}} = 5\,\text{dB}$ has been assumed. This measurement gives an amplifier gain of approximately 7 dB with 1% bandwidth. For comparison, the expected frequency response, due to patch antennas alone, is also shown (shifted upward 7dB to account for the amplifier gain). This patch response was measured on a HP 8720 network analyzer, and shows good correlation with our measurement technique. The reverse gain of the active antenna is also shown, which was measured by rotating the AUT by 90°. This measurement indicates that the device is polarization sensitive and unilateral.

The second active antenna used folded slots [6] and the same resistive feedback amplifier because a wider bandwidth was desired. The bi-directional radiation characteristics of folded-slot antennas allows the circuit to be used as either a transmission or a reflection amplifier (the latter requires a mirror behind the amplifier). As a reflection amplifier, the resulting EIPG is shown in Figure 3b, which gives a peak EIPG of 21 dB and a 10% bandwidth. Since little is known about the folded-slot on thin substrate materials, only a crude guess can be made regarding the antenna directivity. Some elementary arguments gives $G_{\text{ant}} \approx 6$ or 7.7 dB, which gives an amplifier gain of 5.6 dB. For comparison, this cell was tested as a transmission amplifier using the technique in [1]-[3] and the result is shown in Figure 3b. Note that the shapes of thes two curves are very similar. The EIPG is larger for the reflection mode because of larger antenna gain, G_{ant}, which is due to the presence of the mirror. The G_{ant} of the transmission mode is estimated to be 1.6, or 2.2 dB, which gives the amplifier gain of 6.6 dB.

V. CONCLUSIONS

An inexpensive measurement technique has been described for characterizing active antenna reflection amplifiers or radar calibrators. Practical difficulties that are typically encountered in the receiver electronics and antenna isolation have been solved using a simple lock-in detection scheme and a new mixer correction algorithm. This measurement technique will also be used in future bistatic measurements in which the angular dependence of the reflection amplifier response can be tested.

V. REFERENCES

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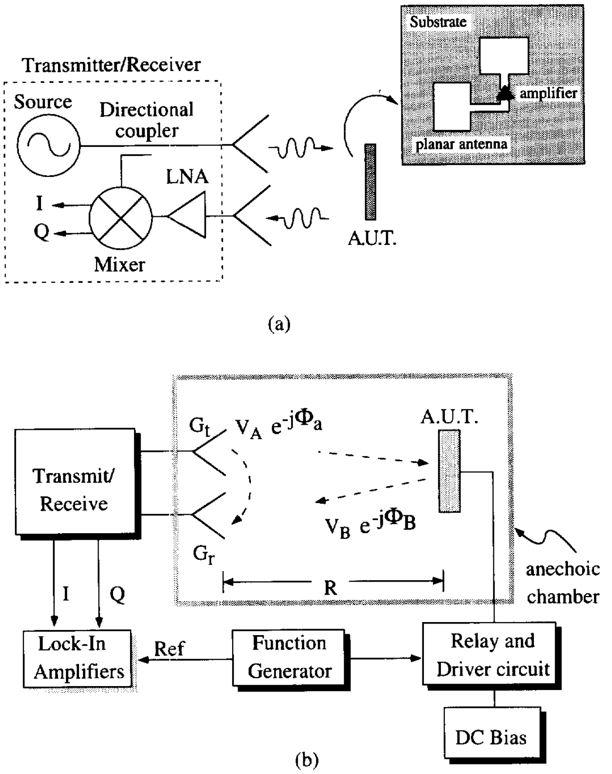
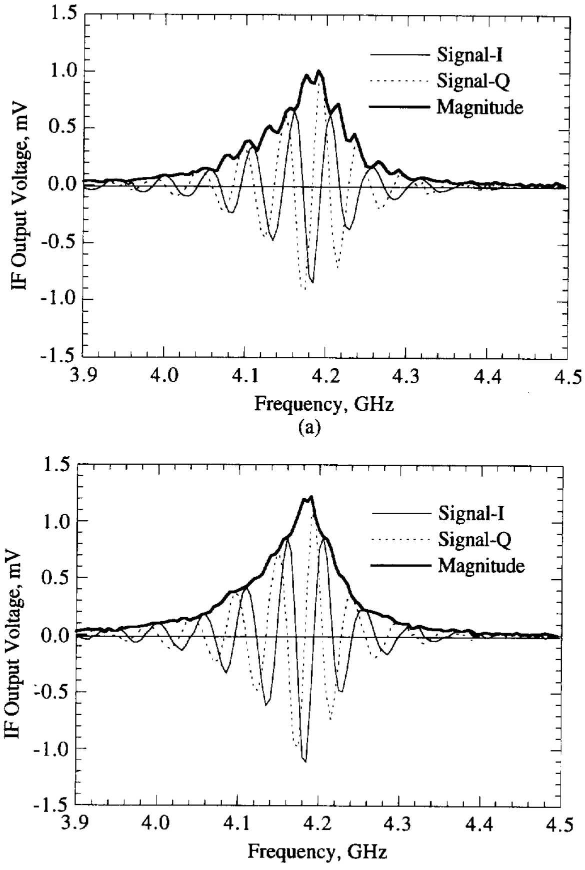


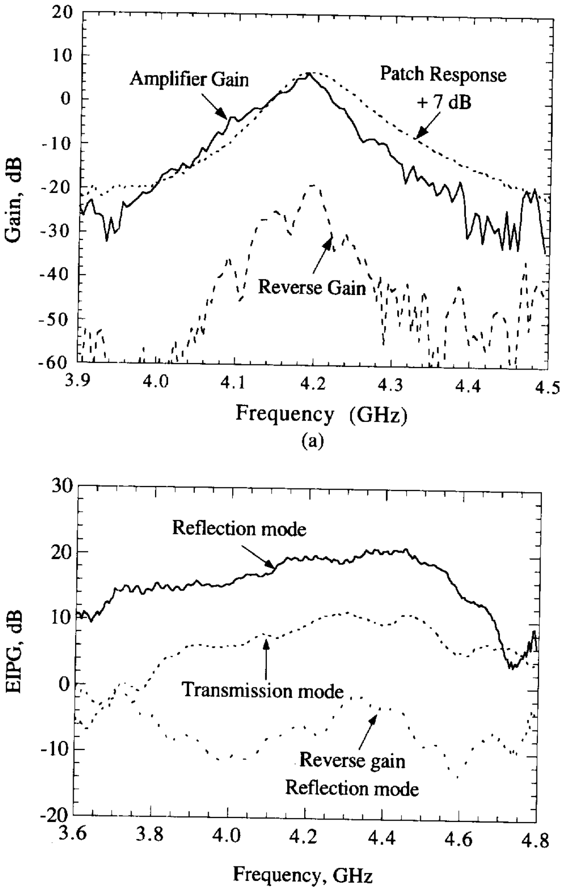
Figure1 : (a) Simple setup for characterizing quasi-optical reflection amplifier of radar calibrators in the far-field. (b) Illustration of the proposed measurement technique. The active antenna bias is modulated by a function generator, and lock-in anplifier are used to sample IF outputs.



(a)

(b)

Figure 2 : (a) Measured I & Q data on a prototype active antenna, and the magnitude calculated from the raw data. The noticeable ripples results from a quadrature phase error. (b) Corrected data and corresponding magnitude after application of the mixer correction algorithm.



(a)

(b)

Figure 3: Measured data for (a) a patch antenna amplifier cell [5]. (b) a wideband folded-slot antenna amplifier cell [6].