DESIGN OF INTEGRATED-OSCILLATOR ACTIVE MICROSTRIP ANTENNA FOR 2.45GHz

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ABSTRACT

The design of an active antenna with integrated oscillator, working at around 2.45GHz was investigated. Voltage series feedback was used to extend the unstable region of a two-port active device and to maximise the input and output reflections. A stripline-fed rectangular patch antenna was considered as output terminal element for the unstable active device. The coupling effects between the antenna and the RF circuit were ignored. The output power at the input of the antenna is optimised with respect to the constraints imposed by the phase noise and the harmonic levels. A calibrated sensor placed next to the radiating edge having maximum voltage was used to predict the characteristics of the active antenna oscillation without affecting the radiating performance. The design goal was met, with fine adjustment and control of the oscillation frequency around the targeted output power.

INTRODUCTION

When an active device is integrated with a microstrip antenna for the purpose of generating a steady state oscillation, it is classified as an oscillator-type active microstrip antenna. The oscillator converts DC power to RF power using the negative resistance characteristics of active devices. An integrated version of such an active antenna has been developed for sensor applications; however, much work in this field has been generated by interest in the potential for spatial power combiner applications to overcome the power limitations of solid-state sources at high frequency. The oscillator consists of an active device in conjunction with a microstrip antenna that simultaneously serves both as a load determining the frequency of oscillation and as an element radiating the generated RF power into space. Proper selection of an operating point of the active device is important for the operational performance.

The active elements can be two-terminal devices [1-3], for example, IMPATT devices and Gunn diodes, or they can be three terminal devices such as MESFET, HEMT, and HBT [4-9]. In general, both advantages and disadvantages are associated with each type of solid-state source. Two-terminal devices are suitable for high power applications at millimetre wave frequencies, but have the disadvantage of low DC to RF efficiency, thus requiring special consideration of heat dissipation in the circuit design. High DC to RF efficiency and low noise figure can be achieved by using three-terminal devices, where other constraints permit this.

Microstrip antennas have advantages of modest size, low profile and planar geometry, leading to low manufacturing cost. The planar structure also lends itself to integration with the associated electronic circuits, e.g. in the form of an active antenna. In the present work, an experiment to develop an active transmitting antenna for wireless local area networks (including Bluetooth) is reported. The antenna was an oscillator-type microstrip active antenna working at around 2.45GHz, linked to a two-port unstable active device. The active device was directly integrated with a rectangular patch antenna, except that a short microstrip line was introduced between the antenna input port and the active device, for measurement purposes. Usually, with such a design process, the feeding line loss would be considered negligible, but it was included in the present work.

DESIGN SUMMARY

The design steps for both the patch and the oscillator were carried out in parallel. The radiation effects of the antenna feed line were introduced on the antenna side and the input impedance variations of the antenna at the feed line were taken as input parameters for the design of the oscillator. Voltage series feedback was employed to maximise the dynamic range of the oscillator output and to insure that operation fell in the unstable region, as is required to satisfy the oscillation conditions.

The antenna was considered with a single-port input (two or more input ports may also be considered) and all the results associated with it, over the frequency band of interest, were transferred to the RF circuit simulator. However, the coupling effects between the antenna and the other RF circuit elements (such as the matching elements and the DC feeder lines) were ignored. The design was carried out firstly by linear simulation to predict the required oscillation frequency and then optimised. Following this, nonlinear simulation was done to predict the phase noise, power performance and harmonic levels.

The characteristics of the antenna (including the feed line) were analysed using the Agilent ‘Momentum’ software package and the oscillator circuit simulated with the Agilent ‘Libra series IV’ package [10]. The design goal (see Table 1) was met, with fine adjustment and control of the oscillation frequency by insertion of a capacitor at the drain pin of the GaAs MESFET active device. It was observed that the range of the oscillation frequency obtained was around 6.87% deviation from the 2.45GHz centre frequency, with low phase noise and acceptable output power.

SENSOR ELEMENT DESIGN AND CALIBRATION

The measured frequency and the forward power at the antenna input port were determined using a sensor calibration factor that had been evaluated when the antenna was disconnected from the oscillator circuit [11]. The sensor was created by a small patch of dimension 3mm x 5mm, placed at the antenna edge developing maximum voltage. The distance between the sensor and the antenna edge was optimised without affecting the input return loss of the antenna port, also satisfying the linearity conditions of the calibration factor required. It was found that a 2mm space (empirically trimmed) was needed to give a coupling of about –16dB between the sensor and the antenna near the resonant frequency of the patch. The sensor patch was also connected to ground via a 50-ohm load, to improve the output match of the sensing circuit. A second pin connected the sensing patch to a coaxial probe at the rear of the board, and this fed the sensor output to a spectrum analyser. The inclusion of the 50ohm resistor ensures that such a sensor will function correctly and also that the output connector of the sensor appears as a relatively well-matched source. This will reduce errors that might be caused by connecting it to a poorly-matched power meter or spectrum analyser. The calibration factor was measured first when the antenna was disconnected from the active RF circuit: this was then reconnected to measure the output power of the oscillator.

Table. 1 Summary of the target specifications and measurements.

Parameter	Units	Specifications	Measured Performance
Opertaing frequency	GHz	2.43	2.42
O/P Power	dBm	10 min	11.5 max
Phase Noise at 100kHz	dBC / Hz	-80	-66
Spurious content	dBC	-80	-60
Harmonics	dBC	-25	-20
Supply voltage	V	5 ± 0.25	5
Supply current	mA	25 ± 2.5	22
Efficiency	%	-	12
Frequency Pulling	kHz	-	213

SIMULATION AND RESULTS

An ATF-10136 GaAs MESFET with noise figure of 0.5 dB at 4GHz was chosen as an unstable two-port active device for the present design. The voltage series feedback was represented by an open transmission line connected to the source of the FET. The linear circuit was optimised for maximum reflections at 2.45GHz for input and output ports. The response of these reflections is shown in Fig. 1. The peak values of S_{11} and S_{22} at the 2.45GHz were found to be 1.9 and 1.3 respectively and these values are acceptable in terms the input and output stability circles required.

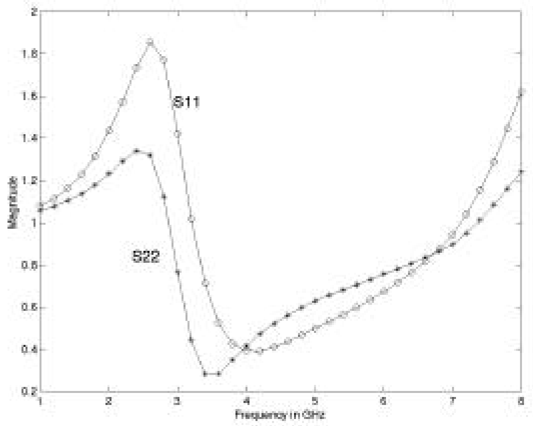

Fig. 1 The response of the S_{11} and S_{22} with series feedback.

The antenna and the RF circuit elements are mounted on Duroid material with the following specifications. The relative permittivity, loss tangent and height of the substrate are 2.55, 0.0018 and 1.524mm respectively. The total area of the finite ground considered for the active antenna oscillator circuit is around 8cm x 5cm. The antenna is considered as stripline fed rectangular microstrip patch. The dimensions of the patch and the feed line are (width 46mm x length 36 mm) and (width 2mm x length 15 mm) respectively. The magnitude and the phase of the return loss at the input of the feed line at 2.45GHz are 0.299 and –147° respectively. The two-port S-parameters between the antenna feed line and the output sensor when the antenna disconnected from the RF circuit are shown in Fig. 2. The corresponding calibrated factor S'_{21} from the measured data when the sensor is placed at 2mm from the end of the radiating patch was computed using the following:

$$S'_{21} = \sqrt{\frac{|S_{21}|^2}{1-|S_{11}|^2}} \tag{1}$$

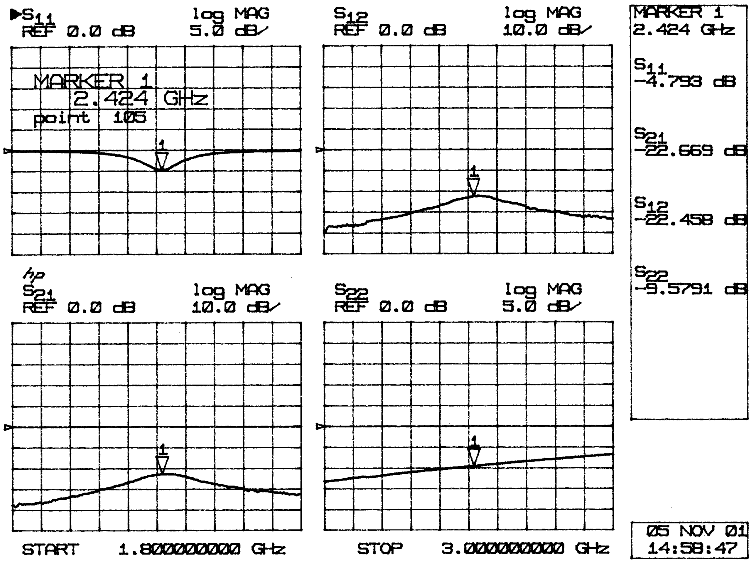

Fig. 2 The two-port S parameters between the antenna input port and the output sensor.

The response of the calibration factor over the band 1.8GHz to 3GHz is shown in Fig. 3. However, the variation of the calibration factor was checked for different distances, varying from 2mm to 4mm, and this shows that the maximum rate of change at 2.45GHz related to the reading taken at 2mm distance is about 0.25dB. The effect of the sensor on the input return loss of the antenna was also checked and found to be less than 0.01dB, dependent on the coaxial feed used.

The antenna input impedance data was transferred to the RF circuit simulator and the resonant condition at the input port of the active devices was observed. Then the input matching circuit was optimised for maximum input power at the antenna port using the non-linear model of the active device. The prototype of the active antenna oscillator circuit, including the sensor, is shown in Fig. 4. The design goal of all of the measurement specification was met, as presented in Table 1. The free-running oscillation and the harmonic contents are shown in Figs. 5 and 6. The harmonic content of –20dB that was obtained is acceptable in practice. The difference between the measured oscillation frequency from the specified one is 1.23%: this represents the errors associated with the RF elements used. Fine adjustment and control of the oscillation frequency around the targeted output power was also achieved by changing the susceptibility of the input antenna admittance. This has been done by connecting the output MESFET with variable capacitor. The oscillation frequency range achieved was within about 6.4% of the targeted value.

CONCLUSIONS

An oscillator-type active antenna, using positive series feedback and working at around 2.45GHz, was designed. The design steps for both the patch antenna and the oscillator were carried out in parallel. The voltage series feedback results in good dynamic range at the oscillator output. The measured frequency and the forward power at the antenna input port, using a calibrated output sensor, gave reliable results without affecting the radiation performance of the antenna and the oscillator circuit elements. The design goals were mostly met.

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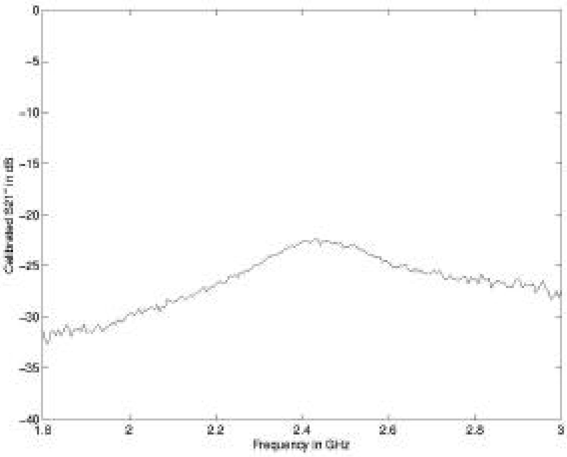

Fig. 3 The calibration factor S'_{21}.

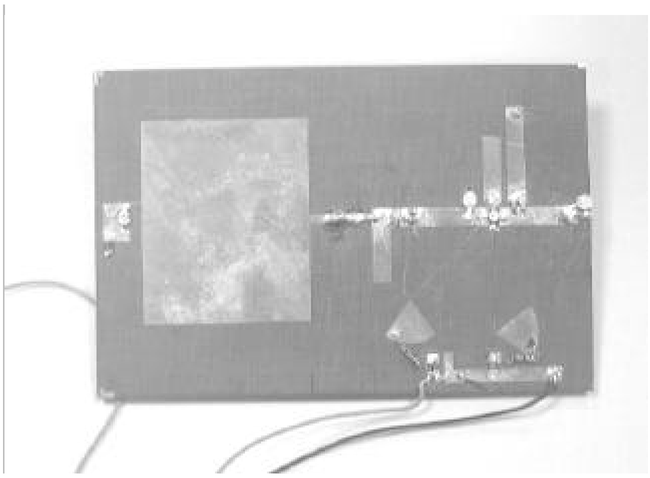

Fig. 4 Active oscillator antenna.

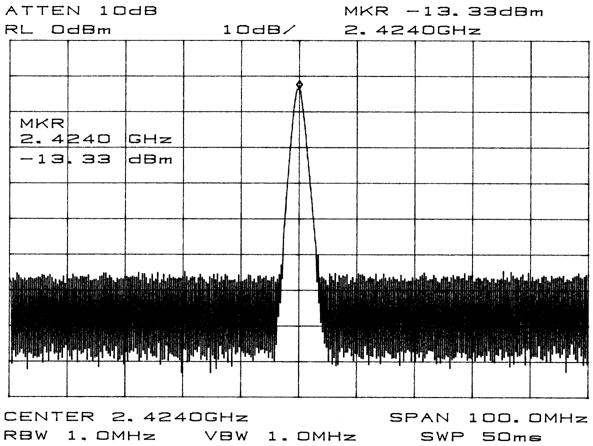

Fig. 5 Free running oscillation

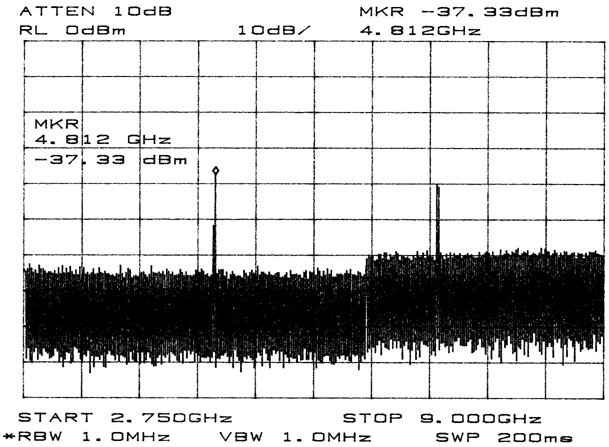

Fig. 6 The measured harmonic content.