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A Novel Low-Noise Downconverter System Using a Microstrip Coupled Transmission-Mode Dielectric Resonator

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Abstract **—A low-noise downconverter system for microwave downlink applications is presented. Although most downconverters with an internally generated local oscillator have been designed utilizing MESFET's and DGFET's, the circuit described herein uses a silicon bipolar Darlington pair as its active device and a dielectric resonator for feedback. Downconverters of the latter type have been realized with noise figures as low as 4.57 dB and conversion gains of 7 dB over an intermediate frequency range from 0.6 to 1.8 GHz.**

I. Introduction

There is currently an increasing interest in downconverter circuits which can be employed in low-noise receiver applications such as those found in commercial radio links, satellite broadcasting systems, and Doppler detectors.

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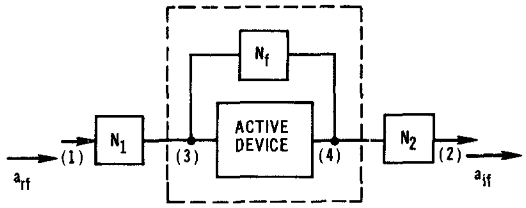

Fig. 1. Circuit configuration.

The application of single- and dual-gate GaAs MESFET's as downconverters has been reported previously [1]–[4] for frequencies in the X-band region. In addition to their advantage of simplicity, these devices have been shown to provide adequate conversion gain and IF bandwidth; however, their noise performance has been found to be a source of concern.

The objective of the effort reported in this paper was to develop a downconverter operating over the 3.7 to 4.2 GHz downlink band which would afford a simple, compact, and easy-to-construct design.

The design is unique in the sense that it utilizes a bipolar Darlington pair amplifier as its active device and dielectric resonator as feedback to provide a source of stable internally generated local oscillator signal power. Additionally, a uniquely synthesized diplexer circuit was developed for the output which provides a wide-band response over the 0.6 to 1.8 GHz intermediate frequency range used.

Design aspects of the downconverter and its circuit description and construction are given in Sections II and III. Experimental results are reported upon in Section IV.

II. Design Considerations

Several fundamental circuit configurations were investigated for the downlink receiver application being considered. A feedback-type structure was selected based on the system constraints involved and a desire for simplicity. This configuration is illustrated in Fig. 1. In this system, the RF signal a_{rf} is injected into port 1, mixed with an internally generated local oscillator (LO) signal created in the feedback device located between ports 3 and 4, and the resultant IF signal is extracted at port 2.

The basic function of networks N_1 and N_2 is to provide for signal matching and filtering at the input, and diplexing and matching at the output of the system. In the downconverter described here, these circuits are composed of passive microstrip elements and chip capacitors.

Several fundamental feedback arrangements may be employed to obtain the internally generated LO power required. These include series, parallel, or reflective feedback. Due to its temperature stability, compactness, tunability, and simplicity, a dielectric-resonator-based design was selected to perform this function [5]. Although this portion of the circuit could be realized with the dielectric resonator placed at either the input [6] or output [7] of the active device, the design developed employs the resonator as a parallel feedback element. This configuration has been found to possess numerous advantages over the others, such as ease of tuning [5], [6], [8].

The basic configuration of the dielectric-resonator feedback network employed in the local oscillator circuit is shown in Fig. 2(a). As illustrated in this figure, the circuit consists of a dielectric resonator placed between two curved microstrip lines. Thus, in this arrangement, there is magnetic coupling between the two

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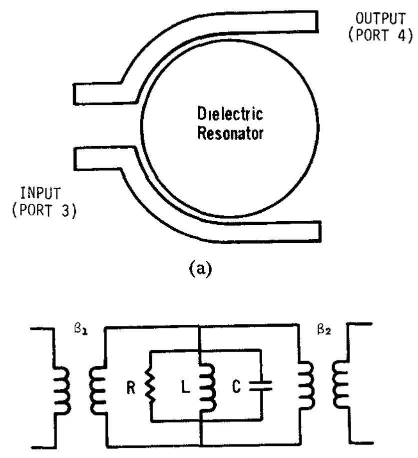


Fig. 2. (a) Dielectric resonator feedback circuit configuration. (b) Equivalent circuit.

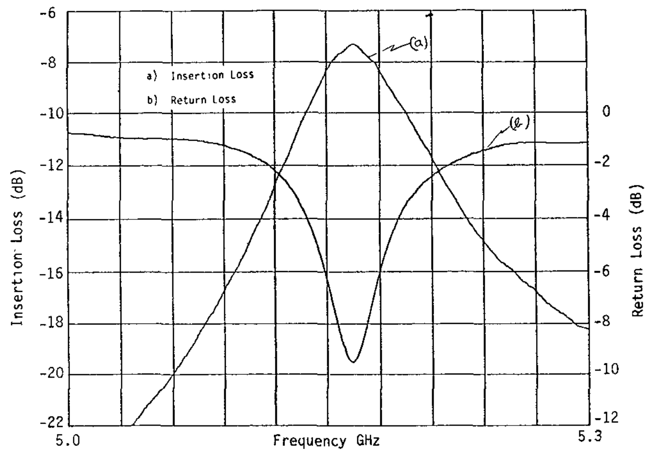


Fig. 3. Dielectric resonator response.

microstrip lines by way of the dielectric resonator. This circuit, which is realized in microstrip, provides a bandpass response with the resonator operating in the $TE_{01\delta}$ mode. Fig. 2(b) is an equivalent circuit representation for this type of coupled structure [6], [9], [10]. A typical measured transmission characteristic of the realized circuit, designated as $S_{21_{Nf}}$, is shown in Fig. 3. From this figure, it can be seen that the insertion loss has a value of about 7.5 dB at the LO design band center of 5.15 GHz. The resonator material is barium titanate and its diameter and height are 1.11 cm. and 0.45 cm, respectively.

The conditions for the initiation of sustained oscillation are satisfied if the small-signal gain of the active device exceeds the total loss of the feedback network N_f and the phase shift around the loop is an integral multiple of 2π radians [6]–[8]. Based on the loss requirement, it is seen that a basic design requirement of the active device is that its small-signal gain must exceed the 7.5-dB loss of the feedback network. It was determined that the Avantek A08 MODAMP offered great promise in this regard. This monolithic silicon bipolar device consists of a single-stage Darlington transistor pair with internal shunt-series resistive feedback. This feedback improves several properties of the A08 [11], [12]. It fixes the Q point of the transistor and eliminates the variation of β, yielding good temperature stability. It also improves the input and output VSWR, gain flatness, and bandwidth.

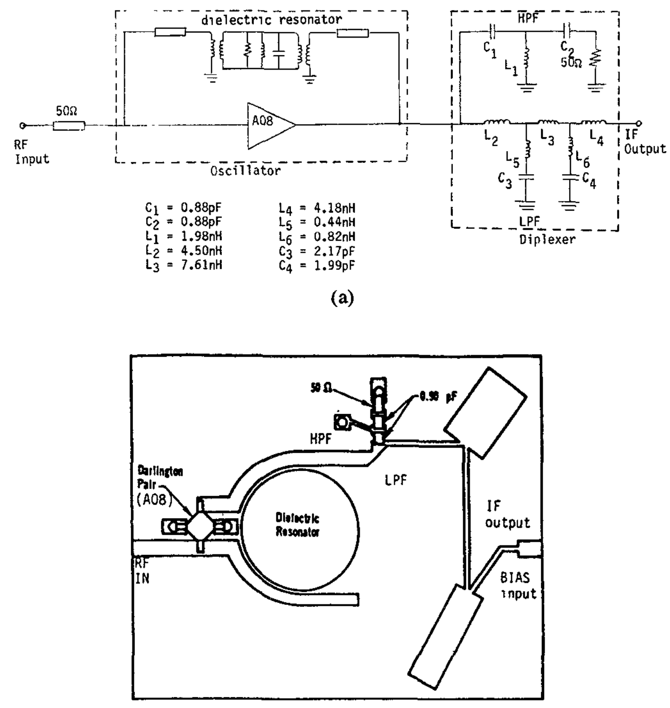


Fig. 4. (a) Schematic of downconverter. (b) Circuit layout of downconverter.

The output network, N_2 in Fig. 1, is configured in the form of a parallel connected diplexer. In this way, it is possible to easily separate the desired intermediate signal frequencies from the LO, RF, and idler frequencies. This diplexer was realized in a parallel high-pass and low-pass configuration, as shown in Fig. 4(a). The low-pass filter was synthesized using a Darlington tandem configuration to achieve a Chebyshev passband with finite loss poles in the stop band [13]. This technique yields inductors as the series elements and a series LC as the shunt elements. The poles were selected such that the synthesized network yielded one shunt arm which was designed to resonate at 5.15 GHz and another at 3.95 GHz for maximum rejection in the LO and RF bands. The microstrip design was constructed by modeling the series inductors as high-impedance transmission lines and the series LC shunt arms as quarter-wavelength (at the LC resonant frequency), open-circuited transmission lines. The high-pass filter was designed to provide a 50-Ω termination for higher frequencies utilizing standard design techniques. The series capacitors were left as discrete elements and the shunt inductor as a shunt, short-circuited, high-impedance transmission line.

III. Circuit Construction

Fig. 4(b) shows the schematic and circuit layout of the downconverter model which was fabricated. In this circuit, the collector and base leads of the Avantek A08 are soldered to the 50-Ω microstrip lines surrounding the dielectric resonator puck, and the emitter leads are grounded via plated through holes. The A08 micro package is 0.1 in on a side. The circuit board consists of 30-mil-thick G10 with a relative dielectric constant of 4.8. The diplexer is located along the upper microstrip line at the output of the transistor-feedback circuitry. The local oscillator frequency can be fine-tuned by adjusting the resonant frequency of the dielectric resonator feedback circuit by changing the distance between the top of the dielectric puck and the lid. This is

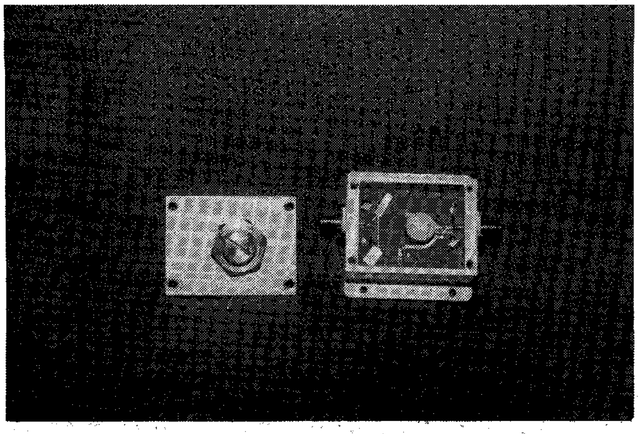


Fig. 5. Downconverter system.

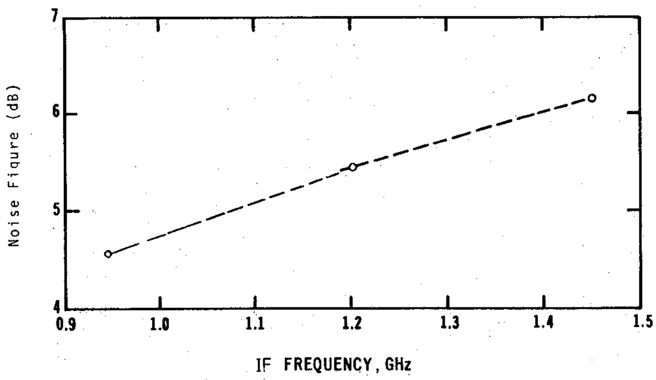


Fig. 6. Noise figure.

accomplished by means of a large screw in the cover of the unit centered over the puck (Fig. 5).

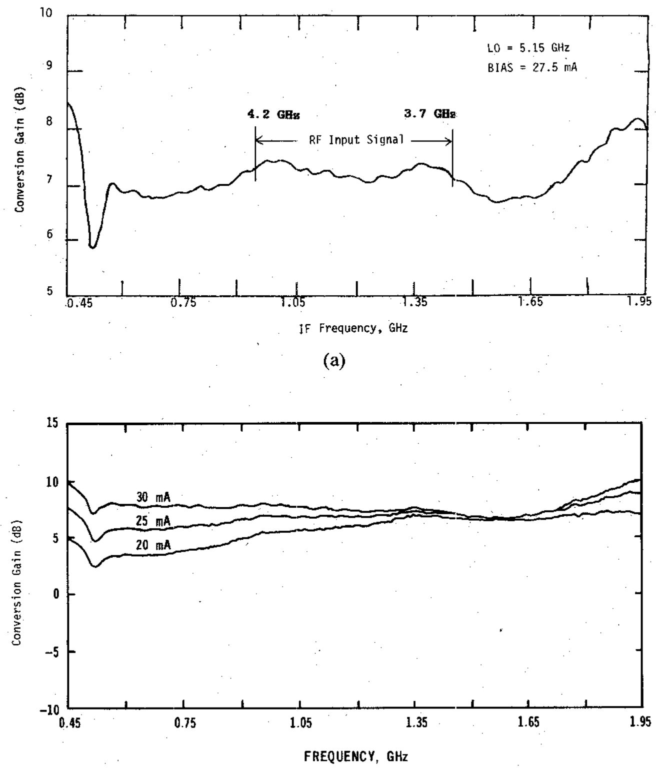
DC bias circuitry for the active device is internal to the A08 circuit; therefore, the only external bias circuitry needed to operate the downconverter is a bias resistor and appropriate filtering. Since the bias is supplied to the output of the A08, the appropriate location for the dc filtering is after the diplexer low-pass filter at the IF output port so that the dc filter only needs to reject the IF frequencies. Bias for the present design is externally applied to the IF port of the downconverter via an HP11590A bias network which is a part of the measurement setup.

IV. Experimental Results

Several downconverter circuits were designed and fabricated as described in the preceding paragraphs. In all cases, the output networks were realized as a shunt-connected high-pass–low-pass configuration while the input network consisted of a length of 50-Ω line.

A photograph of a complete downconverter system is shown in Fig. 5.

Fig. 6 shows a plot of the measured noise figure of the downconverter unit within the specified operating frequency range. Single-sideband measurements were performed using an HP 8970A noise figure meter and an HP346B noise source. The upper sideband was eliminated by the use of a 5.0-GHz low-pass filter at the output of the noise source. These data indicate that noise figures as low as 4.57 dB (SSB) have been attained at the low end of the frequency band and 6.2 dB at the high end. The operating current of the downconverter for these measurements was 20 mA.



(a)

(b)

Fig. 7. (a) Conversion gain. (b) Conversion gain versus dc bias current.

TABLE I
SUMMARY OF MEASURED DOWNCONVERTER PERFORMANCE

RF input signal range	3.7–4.2 GHz
IF output signal range	0.95–1.45 GHz
Noise figure at ambient temperature	4.57–6.2 dB
Conversion gain	7 dB
Frequency response	±0.2 dB over 3.7–4.2 GHz ±0.5 dB over 3.35–4.6 GHz

Fig. 7(a) shows that the measured conversion gain of the downconverter is nominally 7 dB ± 0.5 dB over a 1.2-GHz IF frequency range. Over the 0.5-GHz RF range from 3.7 to 4.2 GHz, the response indicates that the conversion gain ripple is less than ±0.2 dB. The 1-dB gain compression point of the converter occurred at an RF input signal power level of −13 dBm.

Fig. 7(b) shows the measured conversion gain versus dc bias current. This figure clearly demonstrates that an optimum value of gain flatness versus frequency may be obtained by a proper choice of bias current.

Table I presents a summary of the measured performance of the laboratory model constructed for systems which operate in the 3.7–4.2-GHz RF frequency band.

V. Conclusions

A new low-noise downconverter system has been described. This device utilizes a bipolar Darlington pair amplifier and dielectric resonator to provide the internally generated LO signal power. A uniquely synthesized diplexer circuit was developed to provide a wide-band response over the intermediate frequency range used.

The resultant design provides noise figures as low as 4.57 dB and conversion gains of 7 dB.

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Dosimetry of Occupational Exposure to RF Radiation: Measurements and Methods

SANTI TOFANI AND GIOVANNI AGNESOD

***Abstract* —Workers engaged in the operation of RF industrial devices are exposed to electromagnetic radiation in the near-field zone that is characterized by high spatial and temporal gradients. The present paper is concerned with measurement methods and data analyses which allow the evaluation of the electromagnetic field exposure of the operator together with the SAR induced by near-field exposure accounting for the spatial and temporal variations. These methods are applied to the theoretical dosimetry of the occupational exposure to RF radiation emitted by 27.12-MHz plastic sealers. The data obtained are compared with those deducible through a conventional wide-band isotropic field meter.**

I. Introduction

The main features of the conditions of occupational exposure to electromagnetic fields that have to be considered for a correct dosimetry can be stated as follows:

a) temporal nonuniformity of the emission from these devices;
b) exposure of the operator standing near the device in near-field conditions with consequent nonuniform exposure to the E and H fields with reference to the different body parts and lack of proportionality between the electric and magnetic components of the field;
c) operator's mobility near the device because of the lack of a strictly fixed work position.

All these factors affect the mass-normalized power absorption rate (SAR) from the operator's body. The SAR is the parameter on the basis of which the threshold limits of the electromagnetic field exposure contained in guidelines [1] and [2] were defined in terms of external E and H fields [3], [4].

In recent years, many authors, among them Cox *et al.* [5], Conover *et al.* [6], Hietanen *et al.* [7], Stuchly *et al.* [8], and Gandhi *et al.* [9], have dealt with the evaluation of the exposure of workers charged with the operation of industrial devices to electromagnetic fields.

At present, a personal dosimeter capable of a direct measurement of the operator's SAR is not commercially available, although research on this kind of device is in progress [10], [11].

In such a situation, an accurate measurement of the electric and magnetic fields becomes of great importance. Indeed, through a knowledge of the behavior of these parameters, the operator's SAR can be estimated [12].

The theoretical prediction of SAR from only E field data is an acceptable approximation [12] when E fields predominate over H fields.

In the present paper, a measurement instrument which allows continuous monitoring of the electric field strength is shown. Further data analysis for an accurate estimation of the SAR of workers exposed to the near field of time-variable emission sources is presented.

Plastic sealers that are operated at a frequency of 27.12 MHz represent one of the more widespread sources of exposure to intense electromagnetic fields in occupational environments. These are the kind of devices we deal with.

For these devices, the leakage E field is the main electromagnetic factor related to the potential hazard.

The measurement instrument in this case has been used to estimate the component of the electric field only.

II. Instruments and Methods

For the continuous monitoring of the electric field strength to which the operator is exposed, we used an isotropic (± 1 dB) wide-band electric-field probe connected to a battery-powered readout meter calibrated in a TEM cell at a frequency of 27.12 MHz with an accuracy of 0.7 dB [13] and supplying the rms value of the electric field. Such a meter is linked, by an optical fiber 10 meters long, to a repeater connected to the ac power main. The analog output of the repeater is connected to a graphic battery-operated recorder that is supplied. The graphic recorder and the repeater are contained in a shielded box equipped with a low-pass filter connected to the ac power main in order to suppress radiated or conducted RF due to the environmental 27.12-MHz electromagnetic field. The scheme of the instrumental chain is shown in Fig. 1. Measurements were carried out in a firm producing plastic accessories for cars.

The number of plastic sealers present in the firm is 14. The five devices with an output power of 6 kW and the six with an output power of 7.5 kW are not shielded and need to be manually loaded. The three remaining devices, with an output power of 25 kW, are shielded and automatically operated.

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