A MMIC-BASED 75-110 GHZ SIGNAL SOURCE

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Abstract — **This paper describes the design, construction, and testing of a compact W-Band signal source module. The MMIC-based module is an active times-6 frequency multiplier, requiring a 12.5 to 18.5 GHz, 2 mW input signal, which can be provided by any microwave synthesizer or other readily available oscillators. The design includes directional couplers with integrated millimeter-wave detectors on the output for power and reflection monitoring. Output power is voltage-controllable over a 10 dB dynamic range. Test results show 10 dB conversion gain at the maximum output power of about 20 mW across the band.**

I. INTRODUCTION

There is growing interest in W-Band electronics for various applications including automotive and meteorological radar systems, atmospheric radiometry, and even communications. However, development efforts in this area are hindered by the difficulty in finding solid-state signal sources with sufficient power, low spurious tones, and the large bandwidth necessary for general use in a variety of projects. Traveling-Wave Tube oscillators and amplifiers are also available in this frequency range, but the auxiliary requirements for high-voltage power supplies and cooling systems make them inconvenient in many settings, particularly when it is required to mount them on a probe station for on-wafer measurements. The 75-100 GHz Active Multiplier Chain from Millitech (AMC-10-R0000) is compact and capable of providing about 5 mW of power through much of the waveguide band, but it has several dB conversion loss and is unleveled [1]. Finally, Agilent makes a sophisticated millimeter-wave source module (83558A), but it is much larger and has a maximum leveled power of 1 mW [2].

In this paper, we report on the development of a compact, 20 mW, broadband signal source suitable for measurement setups in the 75 to 110 GHz range. A photograph of the module appears in Fig. 1. It makes use of recently developed Monolithic Millimeter-wave Integrated Circuits (MMICs) as well as other commercially available chips. The MMIC approach results in a light, compact module (60 cm^3). Additional features such as an integrated reflectometer and voltage-controlled gain make this a flexible and user-friendly instrument in a laboratory setting.

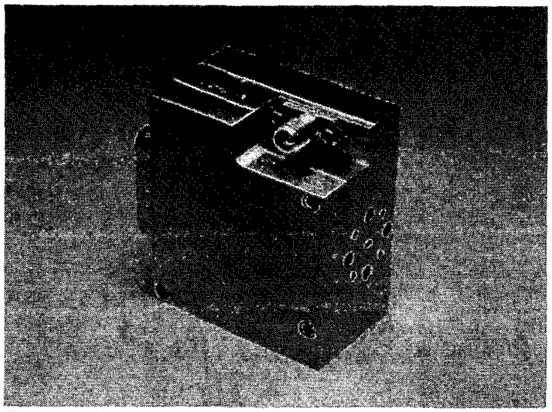

Fig. 1. Photograph of the W-Band signal source. The module dimensions are 5.1 x 4.3 x 2.6 cm.

II. MODULE DESIGN

This module was made possible by the recent development of two key W-Band, integrated circuits: a full waveguide band tripler [3] and a broadband power amplifier [4]. The maximum output power of the tripler is only about 1 mW, so amplification is necessary for practical use. The power amplifier delivers 16 dBm of power across the band. Although designed independently for unrelated projects, the concurrent development of these two chips inspired the idea to combine them in a multi-chip module that would be useful in future millimeter-wave research.

A schematic of the module is shown in Fig. 2. The input signal is fed into a commercially available MMIC driver amplifier and a commercial frequency doubler. The output of the doubler is filtered with a custom designed hairpin-style bandpass filter. It was fabricated by UltraSource Inc. on a 125 μm Alumina substrate. The next chip is a variable-gain amplifier that is used to level the power output of the module. It is nominally biased to deliver about 10 mW from 25 to 37 GHz. This is sufficient to drive the frequency tripler [3] and W-Band power amplifier [4] described earlier. A second bandpass filter blocks spurious signals that may have been generated by the tripler outside of W-Band. The tripler itself has

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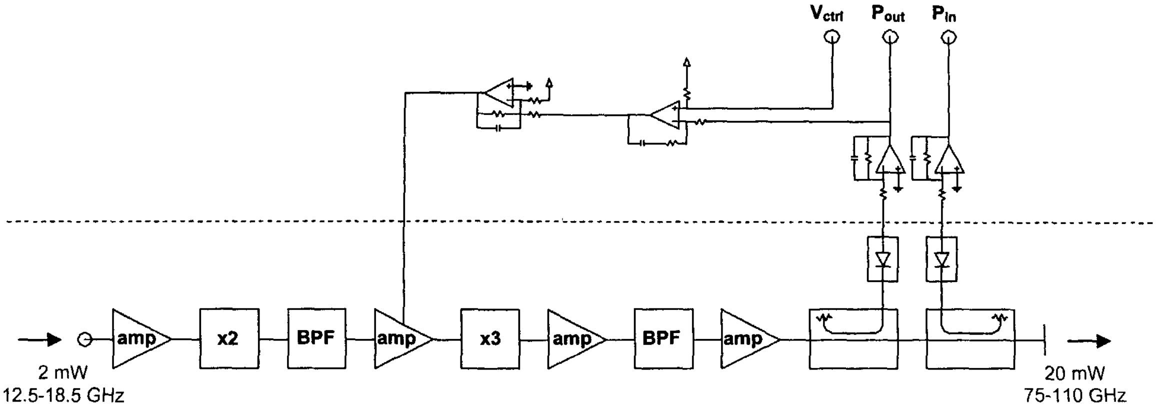

Fig. 2. Schematic of the W-Band source module. Components above the dotted line are on a small PC-Board, while the higher frequency components below the line are mounted in a small cavity inside the split block.

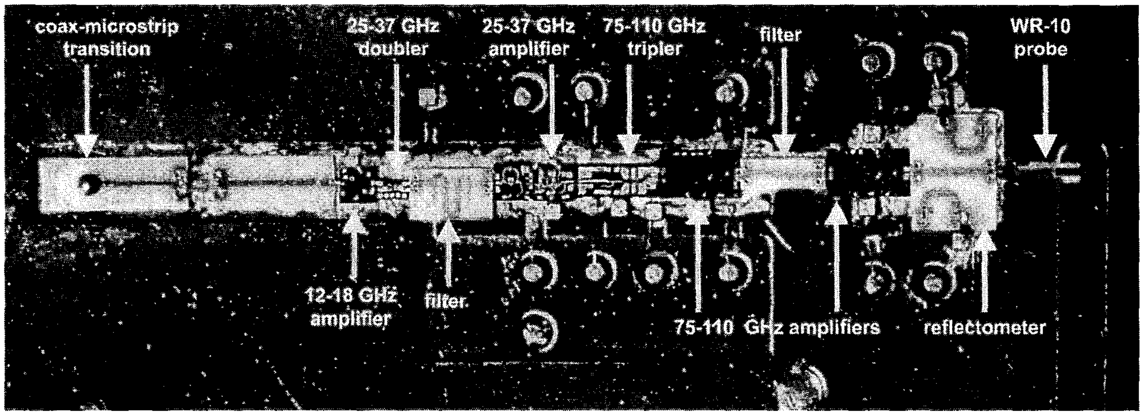

Fig. 3. Photograph of the interior of the split block, showing the coaxial input on the far left, the MMIC amplifiers, multipliers, and passive circuits, and finally the WR-10 waveguide output on the far right. The small holes above and below the row of chips are glass-bead DC feedthrus that connect the bias and control points of the MMICs to the PC-Board on the opposite side of the metal chassis. A schematic of this network is shown in Figure 2.

rejected spurs that fall within W- Band, as described in the reference [3]. A second output amplifier is included to ensure the maximum power is obtained from the module. Finally, the output signal passes through a dual directional-coupler with integrated millimeter-wave detectors. Like the bandpass filters, this microstrip reflectometer was fabricated by UltraSource on 125 μm Alumina. The couplers are codirectional in design, thus overcoming the directivity problems inherent in microstrip backward-wave couplers [5]. Integrated on the substrate are lossy impedance transformers that are designed to match the detector-diodes across W-Band. They are also designed to compensate the natural downward slope of the diode's responsivity so that the detected voltage is relatively independent of frequency and is small enough to keep the diodes in square-law operation.

The module is constructed as a split-block with the dividing plane bisecting the broad wall of the output waveguide. This minimizes loss in the waveguide as the propagating mode has no current across the junction. The MMIC chips lay in an 280 μm deep cavity machined into one of the blocks, as shown in the photograph of Fig. 3. The transition from coaxial cable to microstrip is a perpendicular design in which the coax comes up to the microstrip section from below. Unlike more common end-launch connectors, this geometry maintains a planar top-surface of the block so that the chips can be wafer-probed during initial testing. A novel transition adapter [6] allows

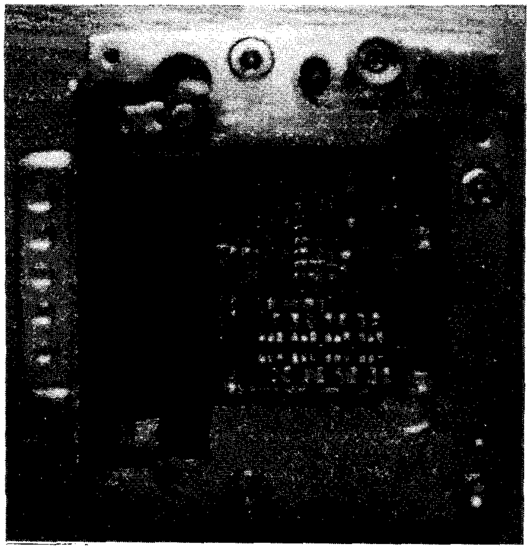

Fig. 4. Photograph of the module with the top-cover removed, showing the PC-Board containing bias and leveling control circuitry.

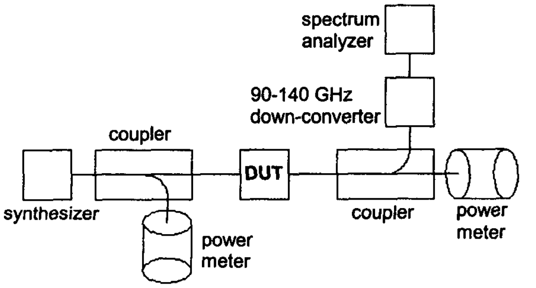

Fig. 5. Diagram of the test setup.

the junction to perform well up into the millimeter-wave band. On the output side, an E-plane, longitudinal probe accomplishes the transition into WR-10 waveguide.

DC signals, such as the bias, gain control voltage, and detected output and reflected power monitors, are connected to glass-bead feedthrus which pass through the block and contact a small PC-Board mounted on the opposite side (Fig. 4). The PC-Board contains voltage regulators for the bias points and op-amps for power control and leveling. The module power supply, control voltage, detected voltages, and several current monitor points are accessible through a 15 pin D-subminiature connector mounted on the PC-Board. A protective metal cover fits over the exposed electronics. Fully assembled, the module is 5.1 x 4.3 x 2.6 cm and weighs 335 grams.

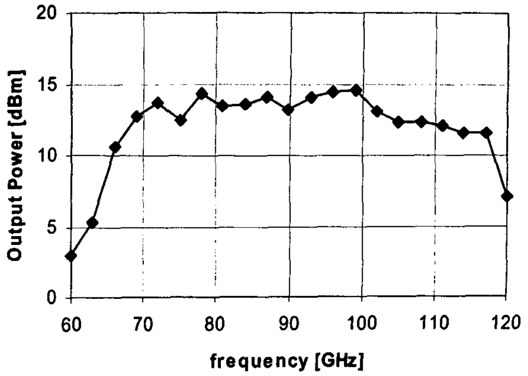

Fig. 6. Output power versus frequency. Input power was +3 dBm, and the control voltage was fixed at -1V for maximum gain.

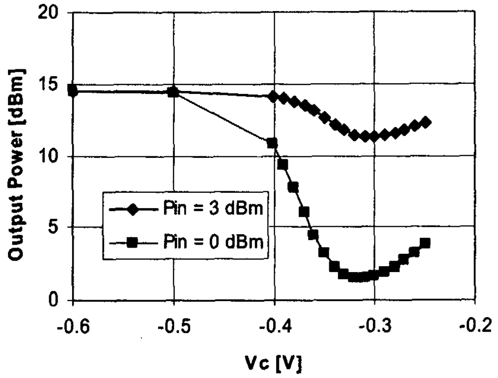

Fig. 7. Output power versus control voltage at 96 GHz.

III. MEASUREMENTS

A diagram of the measurement setup is shown in Fig. 5. The input signal was generated with an HP 8340A Synthesized Sweeper. The input power was monitored with a 16 dB directional coupler and power meter. A 10 dB WR-10 coupler was attached to the output of the module and a W-Band power meter was connected to the thru arm to measure the output power. On the coupled arm was a WR-8 down-converter with a 90 GHz Gunn Oscillator for the LO. The down-converted output was then displayed on an HP 8564E Spectrum Analyzer. In this way, the output spectrum was monitored during the measurement, ensuring that the power meter was reading the main desired signal and not some unusually strong spurious tone. Although no well-calibrated measurement of the harmonics was made, it was clear on the spectrum

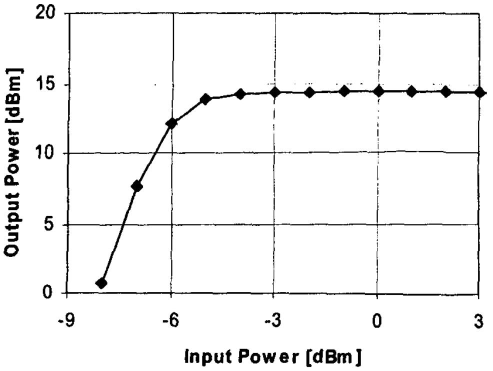

Fig. 8. Output power versus input power at 96 GHz. The gain control voltage was fixed at -1V for maximum gain.

analyzer that the harmonic rejection was on the order of 20 dB or more, at least within the frequency range of the WR-8 down-converter. The loss of the waveguides (typically on the order of 1 dB) and the precise coupling of the couplers was known ahead of time and calibrated out of the measurement, so the data represents the power at the ports of the module itself.

The key results are plotted in Figs. 6-8. With 3 dBm input, the output power was 13.4 ± 1 dBm across W-Band, as shown in Fig. 6. Output power versus control voltage near the center of the band is plotted in Fig. 7. The location of the minimum in the gain curve, about -0.3 V, is consistent with the response of the variable gain amplifier used in the module. The leveling loop was carefully designed to limit the control voltage within the monotonic range of this curve to prevent it from latching up on the low-gain end of the curve. Finally, output power versus input power is plotted in Fig. 8.

Measurements reveal that the reflectometer is not responding correctly to the output power, in turn throwing off the operation of the leveling loop. A careful revision of the coupler and detector matching network is under way, and it is hoped that these features will be restored. However, in spite of these problems this module still represents a step forward in millimeter-wave signal generation. A comparison with three commercial test instruments is made in Table I.

Table I: Comparison of W-Band Active Multipliers

Module	Output Freq.	Power	Conv. Gain	Volume	Leveled
Agilent 83558A	75-110 GHz	+1 dBm	-16 dB	1344 cm^3	yes
Millitech AMC-10-R0000	75-100 GHz	+4 dBm	-6 dB	20 cm^3	no
Spacek AW-6XW	75-95 GHz	+6 dBm	-6 dB	36 cm^3	no
this work	**75-110 GHz**	**+13 dBm**	**+10 dB**	**60 cm^3**	***soon***

IV. CONCLUSION

A compact, 20 mW, signal source for W-Band has been reported. It incorporates recently developed, broadband, millimeter-wave integrated circuits. Tests show that the module delivers about 20 mW of power across W-Band. Such a module is widely useful as a laboratory test instrument.

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