A 5.9-16.3 GHZ AGILE TUNING SOURCE USING WIDEBAND MILLIMETER WAVE MMIC CIRCUITS

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ABSTRACT

An agile tuning VCO assembly which covers a wide tuning range with a single control voltage has been developed. The VCO assembly achieved a frequency output of 5.9-16.3 GHz using a single silicon varactor over the tuning range of 0-20 volts. The VCO assembly was realized by combining specially designed wideband millimeter wave VCO/doubler, mixer and DRO MMIC chips.

INTRODUCTION

Today's EW systems require wide band VCOs to handle threats in multiple frequency bands. Current 6-18 GHz MIC VCO subsystems typically use 4 narrowband VCOs to cover the full band. An alternate approach uses three VCOs and a doubler to cover the same bandwidth. The demanding specifications for frequency drift, tuning linearity and channel isolation, require multiple VCO architectures which result in complex microwave assemblies. Also, controlling frequency drift due to temperature variations requires using separate proportional heaters making the multiple VCO subsystem even more complex.

A simple MMIC based approach is proposed here to meet general purpose wide band EW source requirements using a single VCO. This approach in combination with on-chip heaters [1] would allow for temperature stabilization while reducing overall size and complexity.

APPROACH

Several successful techniques have been reported in the literature demonstrating significant VCO tuning bandwidth [2-6]. Most of these techniques concentrate on only the direct VCO tuning bandwidth.

The present approach combines multiplied and heterodyne frequency conversion schemes, implemented with MMICs to achieve even wider tuning bandwidth than could be achieved with a VCO alone. A block diagram of the system is shown in figure 1. The method starts by designing a Ku-band VCO which tunes from 15-20 GHz using an external silicon varactor. A silicon diode is used due to its low post tuning drift characteristics. The VCO is followed by an on chip frequency doubler to provide an output frequency of 30-40 GHz. Using a microstrip edge coupled filter, the output from the doubler is then filtered rejecting the VCO fundamental signal. The filtered 30-40 GHz doubled output is then downconverted using a wideband millimeter wave MMIC mixer.

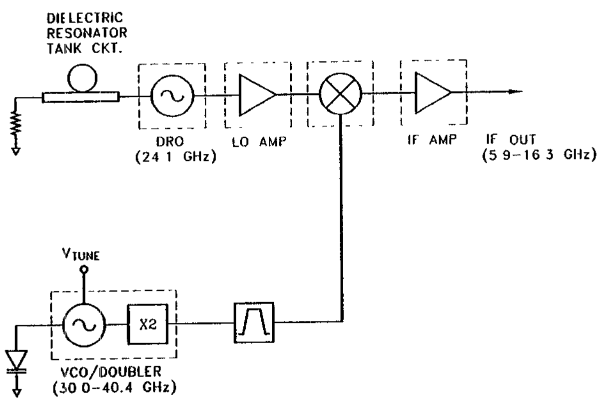

Figure 1 - Block diagram of the 5.9-16.3 GHz voltage controlled source.

The local oscillator used for the down conversion is a MMIC MESFET oscillator operating at 24.1 GHz which uses a dielectric resonator for good frequency stability and phase noise. The DRO output drives a K-band two stage MMIC amplifier which increases the output level to that required for the mixer to achieve low conversion loss. The IF output of 5.9-16.3 GHz from the mixer is the desired output band. By choosing the LO frequency the output band can be shifted up or down in frequency to meet a wide variety of needs. This oscillator topology results in a source capable of a bandwidth exceeding an octave from a single RF port without any need for band switching multiple VCOs.

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VCO CIRCUIT DESIGN

A high frequency VCO chip was developed which utilizes 0.5 um MESFET technology to implement a wideband negative resistance oscillator and an integrated buffer-doubler circuit. The oscillator active device was modeled using a small signal equivalent FET circuit. A linear S-parameter analysis program was used to predict the region of negative resistance and optimize this parameter over the range of 15-25 GHz. A 150 um gate width FET was chosen to enhance the upper frequency capability of the oscillator. A common source topology with capacitive feedback was used to provide the necessary negative resistance. The feedback was set by using MMIC bond pads which can be connected with a wire bond to adjust the value of feedback capacitance. Since the capacitance required is typically .05 to .15 pF, this is an accurate way to control feedback. The capacitance of the bond pad is less sensitive to process variation than MIM capacitors.

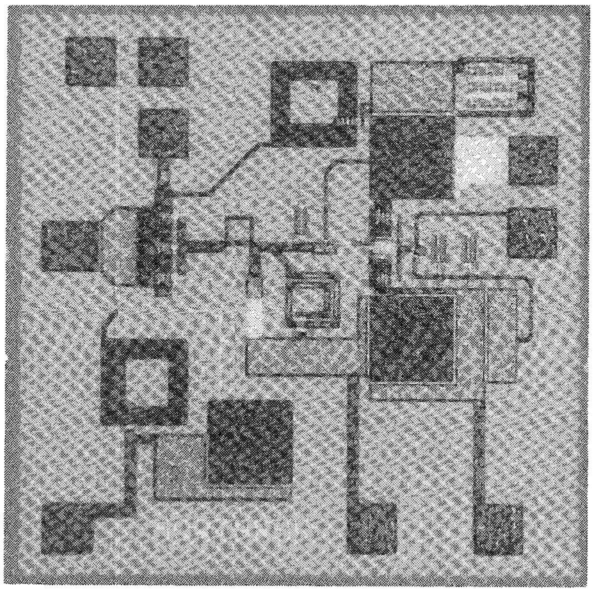

Figure 2. MMIC VCO chip with frequency doubling buffer amp.

Wideband tuning of the VCO is achieved with the use of an external discrete silicon hyperabrupt doping profile tuning varactor, which is wire bonded to the MMIC VCO/doubler chip. The gate of the oscillator device is resonated with the connecting bondwire and varactor to provide the wide tuning range. Both the oscillator and varactor bias circuits are integrated onto the MMIC chip to minimize additional external component requirements. Since the varactor is wire bonded to the MMIC the operating band can be adjusted either up or down. The distance between the varactor and the MMIC VCO chip was set to 25 mils to provide a 15.0-20.2 GHz fundamental tuning range. Using a distance of 15 mils produced fundamental output frequencies up to 24.9 GHz.

The VCO chip shown in figure 2 uses a FET buffer amp which provides a dual function of load isolator and frequency multiplier. The buffer amp consists of a 75 um FET biased at Idss which provides a strong second harmonic due to the forward conduction of the gate during positive signal excursions.

The small device periphery also allows the buffer amplifier to saturate at a low drive level estimated to be about +6 dBm. The buffer amp was intentionally designed with small gate width to allow the buffer amp to act as a limiter to flatten output power at the saturated output level. This results in good power flatness at the second harmonic. The VCO chip was tested alone and its performance is shown in figure 3.

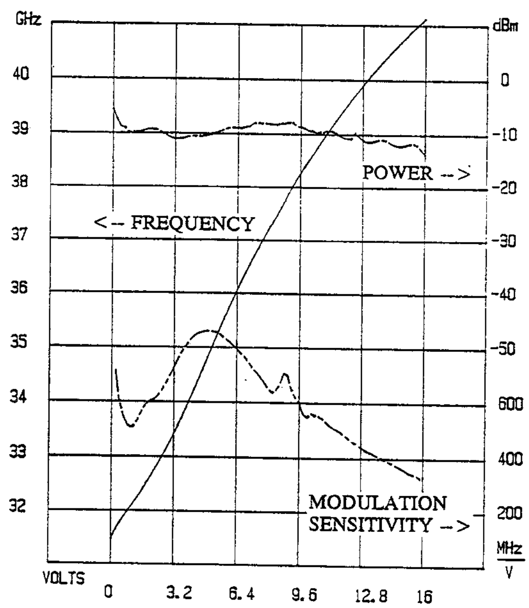

Figure 3. Measured frequency and power of MMIC VCO chip.

Using the second harmonic, output frequencies up to 50 GHz have been achieved at -10 dBm. The VCO chip requires a single 5 volt supply and draws 48 mA of current. The MMIC VCO chip measures 46 x 46 mils (1.2 x 1.2 mm).

MILLIMETER WAVE MMIC MIXER

A wideband MMIC millimeter wave double-balanced mixer was designed and fabricated to cover an RF band from 15 to 50 GHz and an IF band from 3 to 21 GHz. The mixer schematic is shown in figure 4. The actual MMIC chip, shown in figure 5, uses two distributed baluns for the RF and LO ports respectively, MIM capacitors for the IF diplexing circuit, and 4 interdigited diodes in a ring quad configuration.

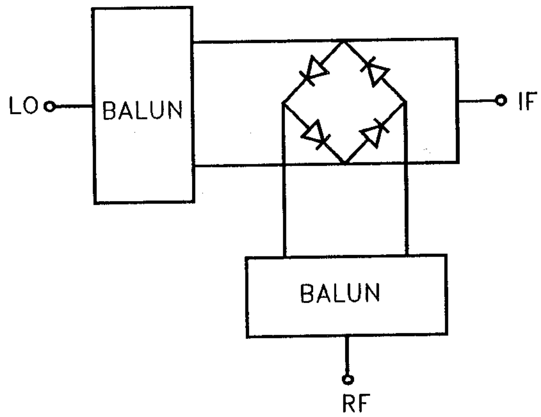

Figure 4. Millimeter wave MMIC mixer simplified schematic diagram.

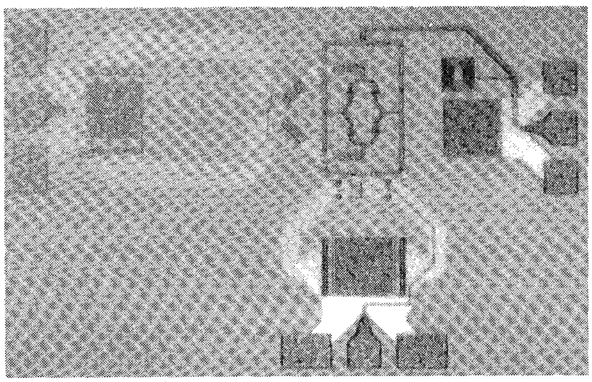

Figure 5. Fabricated millimeter wave mixer.

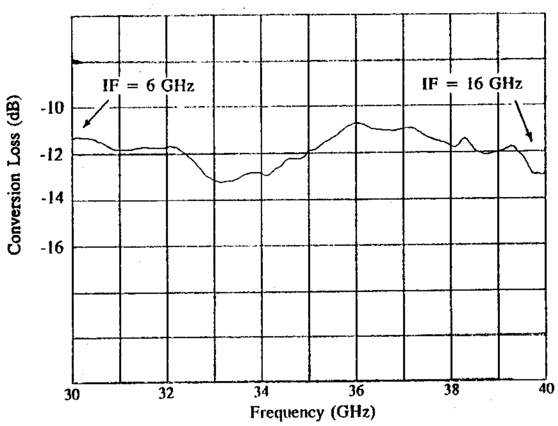

Figure 6. Measured conversion loss of MMIC mixer using an LO at 24 GHz with +10 dbm drive level.

The diodes have a junction capacitance of 0.05 pF and a series resistance of 20 ohms providing an average conversion loss of 12 dB. The double-balanced configuration gives 20 dB LO to IF isolation and 30 dB RF to IF isolation as well as very good suppression of high order spurious products. The wide bandwidth of the IF port makes it possible to downconvert a millimeter frequency band into the full 6 to 18 GHz microwave band. The conversion loss of the mixer, shown in figure 6, was measured over the RF band of 30 to 40 GHz using an LO frequency of 24 GHz. The MMIC mixer chip size is 46 x 71 mils (1.2 x 1.8 mm).

DRO CIRCUIT

A DRO was designed using a 150 um MESFET which delivers a typical output power of 8 to 10 dBm at 24 GHz. A series capacitive feedback topology provides a wideband negative resistance suitable for resonating with an external 50 ohm microstrip line which is coupled to a dielectric resonator for frequency stability. The MMIC DRO chip measures 46 x 46 mils (1.2 x 1.2 mm). An 18 to 26 GHz LO amplifier was used to provide buffering and increase the LO drive signal of the DRO.

MEASURED PERFORMANCE

A working prototype consisting of the VCO, mixer, DRO and buffer amp chips mounted onto a metal carrier plate was built and tested. A photo of the VCO assembly is shown in figure 7. All the MMIC chips have been designed to operate on 5 volts and the total current draw is 375 mA. The MMIC subassembly has been measured for RF frequency and power output. The results are shown in figure 8. This result represents a 2.76:1 tuning ratio. Due to the use of a

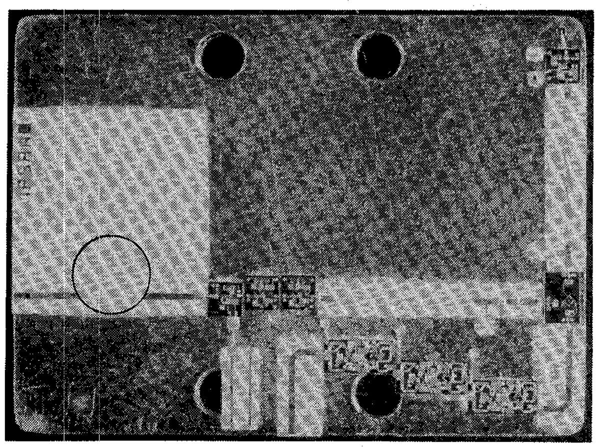

Figure 7. Photo of 5.9-16.3 GHz wide band VCO assembly.

mixer in this approach the output does contain some spurious outputs. The spurious signal levels were measured to be -30 dBc at 6 GHz and gradually reducing to -22 dBc at 16 GHz.

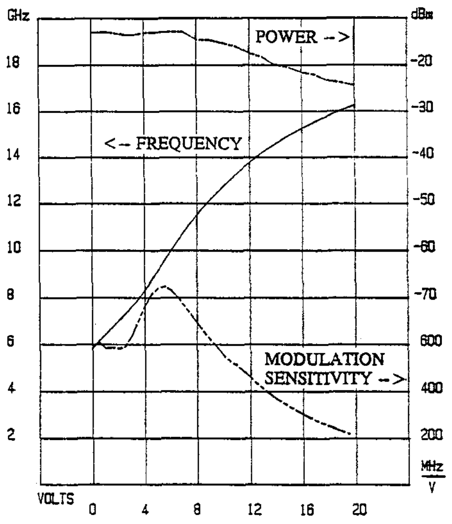

Figure 8. Measured tuning response and power output of complete VCO assembly.

FUTURE DEVELOPMENTS

Presently the VCO assembly spurious levels are limited by the 2LxR spur suppression of the mixer chip. One way to improve the spurious performance is to use the VCO as the LO signal and to inject a low level RF input at 24 GHz. With this change the dominant spur would now be 2RxL. By decreasing the RF input level the spurious performance will improve. For each 1 dB of RF input power drop the spurious level will drop by 2 dB. The power however cannot be decreased too much since the post conversion 6-18 GHz IF amplifier needed, will increase the noise floor. To implement this approach a 30-40 GHz LO amp is presently under development. The amplifier is required since the MMIC VCO output power is insufficient to drive the mixer.

Existing programs use the four digitally tuned oscillator MIC module shown in figure 9. The photo shows the relative size comparison of the two approaches. This architecture can be further improved to cover 6-18 GHz by using dual varactors in the VCO circuit.

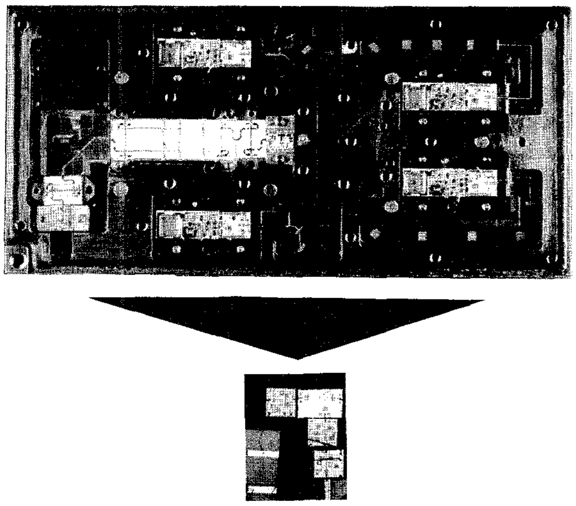

Figure 9. Relative size comparison of MIC VCO module vs MMIC VCO assembly.

CONCLUSION

A MMIC based agile 5.9-16.3 GHz VCO source assembly has been demonstrated. The MMIC chips utilize a high throughput 0.5 um ion implant MESFET technology to realize a low cost, small size wideband source. This approach is useful when the spurious rejection requirements are moderate. Using this approach significantly reduces assembly time and labor intensive manual circuit tuning.

ACKNOWLEDGMENTS

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