Compact High-Powered Frequency Multipliers for S-Band Telemetry Frequencies

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ABSTRACT: This paper describes reliable solid-state stripline frequency multipliers that develop an output power in excess of 16 watts at S band. An overall efficiency of 46 percent is achieved for two cascaded doublers that have adequate varactor diode temperature derating to permit continuous operation at 90°C heat sink temperature. The stripline construction techniques use solid dielectric with 1/8-inch ground plane spacing permitting an extremely rugged compact package. The wide dynamic bandwidth of these devices permits the design of high linearity, wide-band, solid-state telemetry links. A technique is described that permits parallel operation of varactor diodes with inherently high isolation that ensures equal power sharing. The general design steps are also discussed. Data are presented that illustrate input–output power linearity, temperature stability, spurious signals, and bandwidth.

Introduction

In the past year, we have experienced an increase of activity in the 2200- to 2300-MHz telemetry band. The trend in each of these applications is for higher power and wider bandwidths in smaller and smaller packages while still increasing the overall reliability. These requirements we believe are best satisfied by an all solid-state telemetry transmitter. Until recently, the major problem in a high-power S-band transmitter has been the amplification and frequency multiplying of the CW signal. The latter part of this problem will be discussed in the remainder of this paper.

Objectives

The major objectives that guide our design approach to a multiplier chain are tabulated as follows:

1) high reliability
2) maximum efficiency
3) minimum tuning controls
4) easily packaged and adaptable to high volume production.

Reliability is of prime importance and this in turn dictates several restrictions. For instance, we limit the maximum operating diode chip temperature to 150°C in all designs. The use of solid dielectric stripline circuitry contributes to high reliability by eliminating individual lumped circuit components. Designing for maximum efficiency also contributes to a highly reliable design in that the power dissipated in the diode is minimized. Also, the drive power required from the transistor power amplifier is reduced, thereby lowering the overall power input to the transmitter.

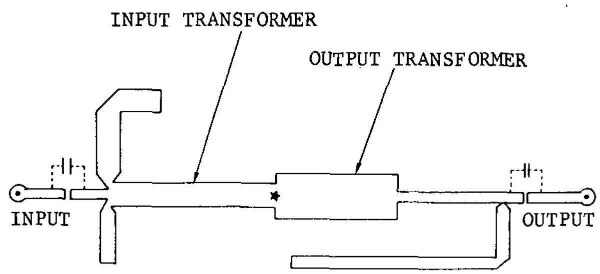

Fig. 1. Typical multiplier circuit.

The dynamic bandwidth of the multipliers is sufficient in that a minimum number of tuning controls is needed to tune the entire telemetry band. By using solid dielectric stripline construction exclusively, the design lends itself to high volume production at minimum costs because the circuits are photoetched and very reproducible.

Circuit Description

A typical multiplier circuit is shown in Fig. 1. The input matching transformer is one-quarter wavelength long at the output frequency and the characteristic impedance is chosen to match the real part of the diode impedance to 50 ohms. The two open circuit stubs on the input transformer complete the input match and provide filtering of the second and third harmonic signals. The output transformer matches the real and imaginary diode load impedances to 50 ohms. The open circuit stub on the output line acts as a filter at the input frequency. The dotted line capacitors in the input and output lines are uncased ceramic chip coupling capacitors. These capacitors isolate the entire circuit so that a dc bias voltage can be developed by the varactor diode.

A typical multiplier chain consists of two unilateral[1] circuits in series as shown in Fig. 2.

Power splitting and combining techniques using stripline 3-dB directional couplers are employed to sum the outputs from two or more varactor doublers; thus, a diode can be selected which will optimally handle the required power per stage. This technique permits reliable thermal

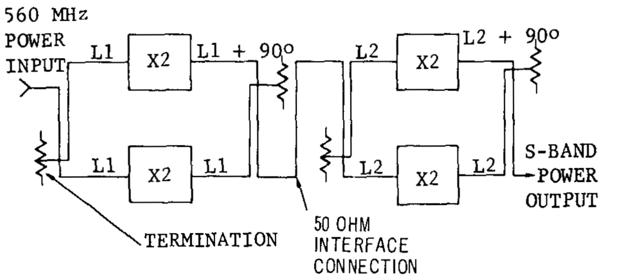

Fig. 2. Schematic diagram of the stripline X4 varactor multiplier chain.

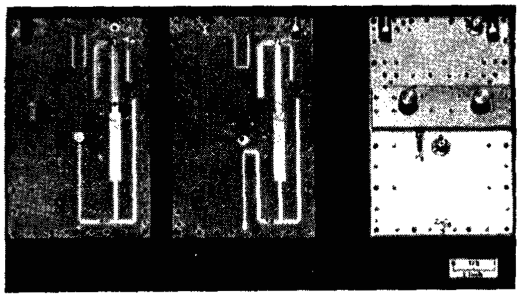

Fig. 5. Unilateral doubler circuit.

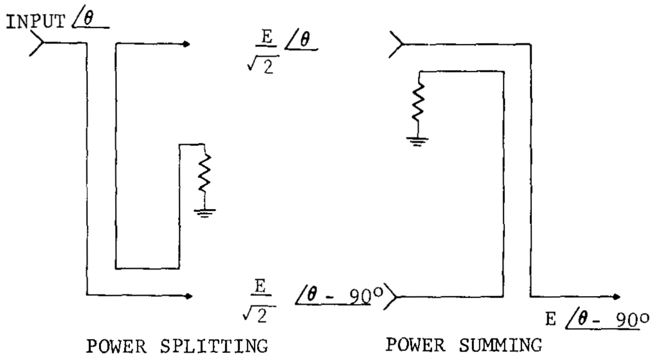

Fig. 3. Power splitting and power summing.

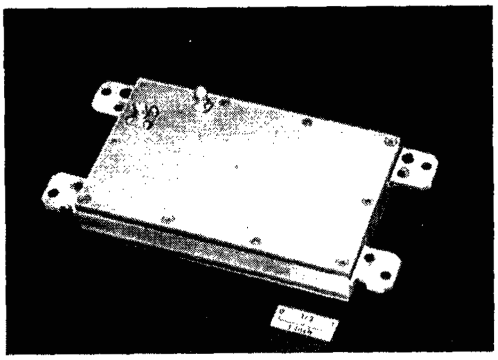

Fig. 6. Two doublers mounted on a common heat sink.

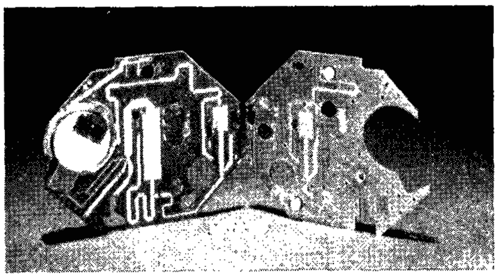

Fig. 7. X4 frequency multiplier including circulator.

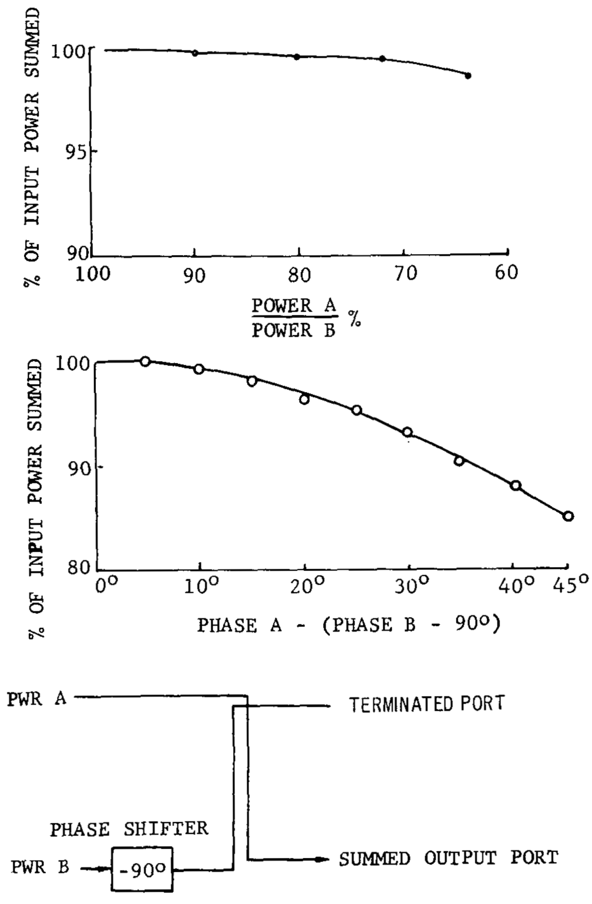

Fig. 4. Two-way power summer test results.

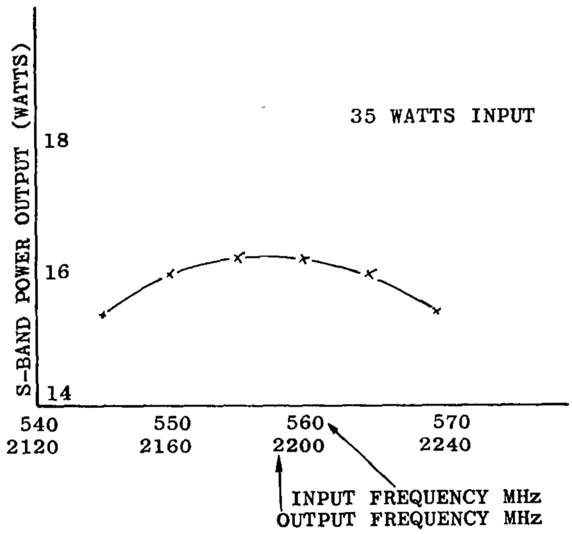

Fig. 8. Power output versus frequency for two unilateral doublers.

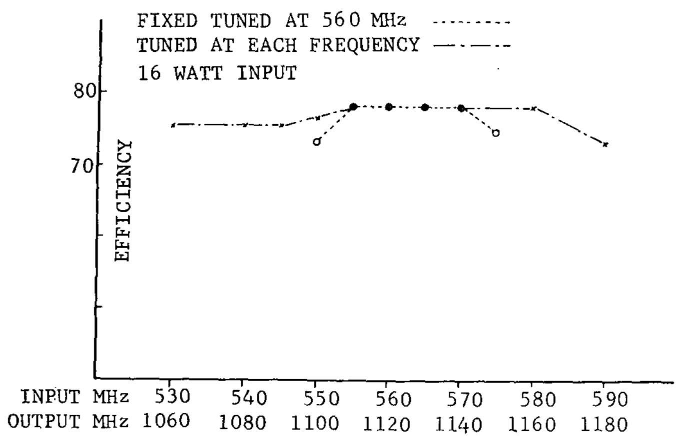

Fig. 9. Efficiency versus frequency for 560- to 1120-MHz doubler.

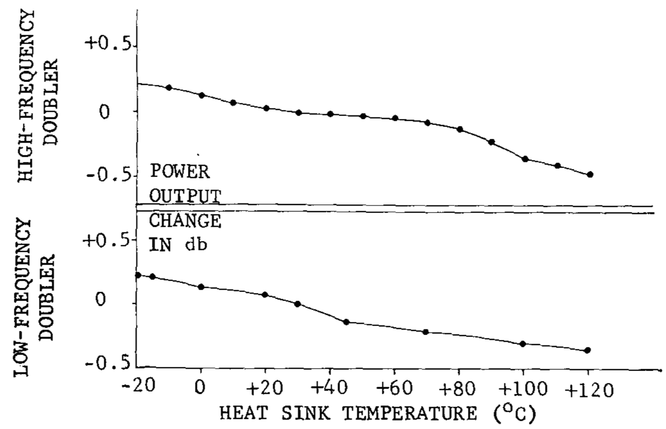

Fig. 12. Power output variation as a function of heat sink temperature.

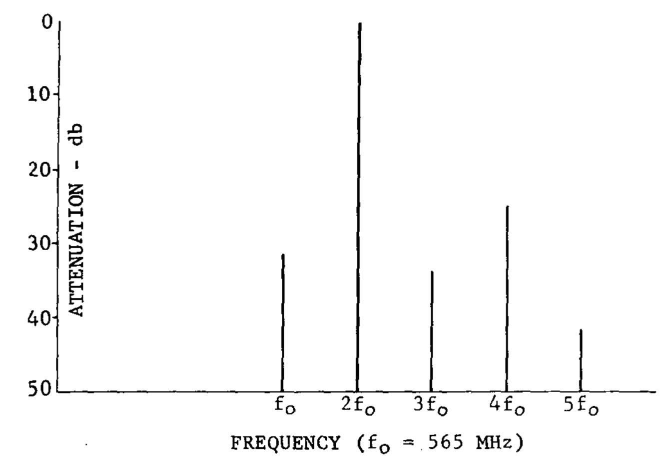

Fig. 10. Graph of coherent spur levels in a unilateral X2 stripline frequency multiplier.

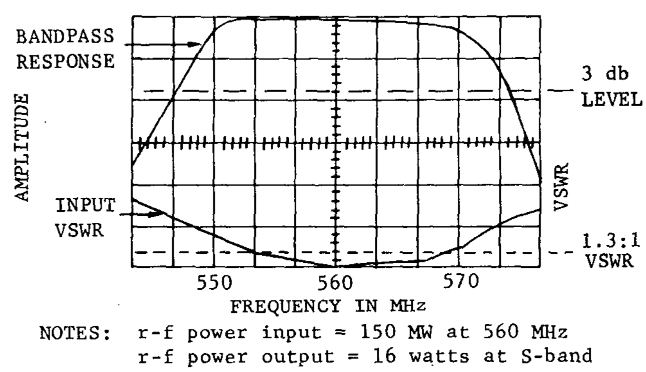

Fig. 13. Frequency response of the wideband transmitter power amplifier and two unilateral doublers.

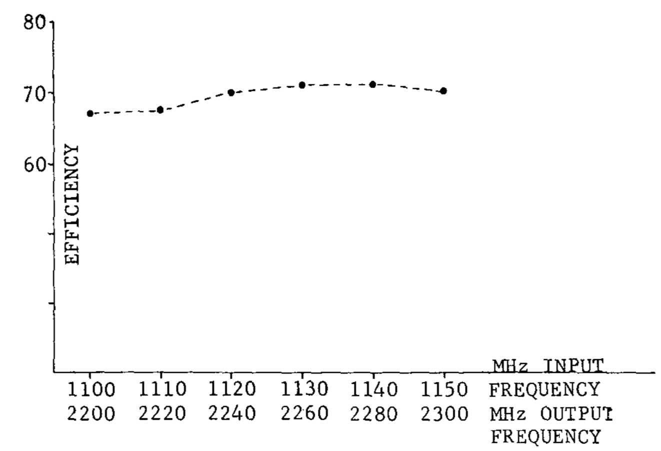

Fig. 11. Efficiency versus frequency for 1120- to 2240-MHz doubler.

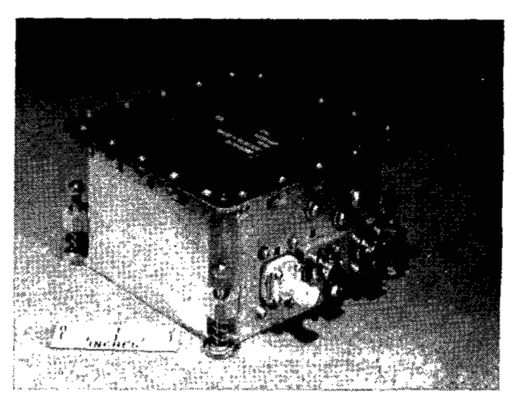

Fig. 14. Five-watt FM S-band transmitter.

derating of each diode and minimizes output power variations due to environmental stresses. This approach is employed in the design of *S*-band telemetry transmitters for five sponsored programs ranging in output power from 5 to 12 watts. The power splitting and summing technique employing 3-dB directional couplers has the following properties:

1) Isolation between summing ports. This eliminates instability caused by interaction between summed multipliers and also constrains each multiplier to share the power load. A failure of one circuit will not cause "runaway" failure in the remaining multiplier.

2) Minimum sensitivity to phase and amplitude variations between the multiplier circuits.

3) Negligible insertion loss.

A 3-dB directional coupler connected as a power splitter and as a power summer is shown in Fig. 3. Such a coupler is easily constructed in stripline form. The approximate volume per coupler at 560 MHz is 0.2 cubic inch. Measurements on individual couplers have shown insertion loss of 0.1 dB and the coupling is maintained within ±0.1 dB over a 30 percent bandwidth. A minimum of 29-dB isolation was measured on a 560-MHz coupler from dc to 1 GHz. Fig. 4 shows the power summing test results which indicate that the power summing efficiency of the 3-dB coupler dropped insignificantly to 99 percent for either a 30 percent unbalance of power sources or for over 10 degrees difference in the phase of the power sources. In addition to the isolation between multipliers, these circuits provide a "unilateral" behavior. The unilateral characteristic is such that the input impedance of each summed doubler stage is independent of the loads presented to it. The degree of independence is a function of the diode balance obtained in each of the single doubler circuits. With the all-stripline type of construction used in these circuits, little difficulty is encountered in obtaining the required phase tolerances.

Performance Data

Fig. 5 illustrates a disassembled "unilateral" doubler and a fully operational breadboard. A dielectric separator is employed between the circuits to complete the assembly of the directional couplers. Fig. 6 shows a mock-up of two high-powered doublers mounted to a common heat sink. Fig. 7 shows a unilateral output doubler driven by a single diode low-frequency doubler. This design includes a drop-in stripline circulator and represents what we believe to be the optimum in package density. Performance curves for two "unilateral" doublers are shown in Fig. 8. The input power in this case was 35 watts at 560 MHz and a nominal 16 watts was developed at *S* band for a conversion efficiency of 46 percent. Figs. 9 and 10 illustrate the performance of individual doublers for 560 to 1120 MHz, while Fig. 11 illustrates the performance of an individual doubler for 1120 to 2240 MHz. The performance of individual doublers as a function of varactor diode heat sink temperature is shown in Fig. 12.

Fig. 13 is a swept frequency response for a 560-MHz amplifier followed by two "unilateral" doublers that develop 16 watts of CW power at *S* band. Note that 100 MHz or the equivalent of the full 2200- to 2300-MHz telemetry band is covered without tuning adjustments.

Fig. 14 illustrates one of the smaller transmitters now under development. This FM transmitter develops a minimum of 5 watts at *S* band in a 75 cubic inch package.

References

[1] J. W. Gewartowski, "Unilateral frequency multiplier circuit," *Proc. IEEE*, vol. 52, pp. 1749–1750, December 1964.

Lester J. Moser was born in Elgin, Ill., on June 6, 1935. Following service in the U. S. Air Force he attended the University of Illinois, Urbana, and received the B.S.E.E. degree in 1962.

He joined Motorola Inc., Scottsdale, Ariz., in June 1962, working as a Systems Engineer with the Telecommunications Group on the Goddard Range and Range Rate Tracking Systems. In 1965 he joined the CW Transponder Section and was assigned the task of investigating the techniques and uses of stripline when applied to power amplifiers, high-powered frequency multipliers, and other components of an all solid-state high-power telemetry transmitter. After the study phase he was assigned to several programs to apply the new techniques. Presently he is studying the application of stripline techniques to a solid-state power amplifier at *S*-band frequencies.

Mr. Moser is a member of Eta Kappa Nu.

James W. Ross (S'56–M'62) was born in East Tawas, Mich., on February 11, 1933. He received the B.S.E.E. degree from the Michigan College of Mining and Technology, Houghton, in 1956.

From 1957 to 1959 he served as Lieutenant in the U. S. Air Force at Wright-Patterson Air Force Base, Dayton, Ohio. He was technically responsible for microwave tube research and development contracts. He joined Litton Industries, Electron Tube Division, San Carlos, Calif., in 1960, acted as Project Leader directing development of a superhigh-frequency, high-powered, crossed-field amplifier. He also worked as Applications Engineer being responsible for traveling wave tube devices. In 1963 he joined the Bendix Corporation, Research Laboratory Division, Southfield, Mich., and worked as Project Leader responsible for two VHF traveling wave tube projects. In 1965 he joined Motorola Inc., Government Electronics Division, Aerospace Center, Scottsdale, Ariz., and is presently Project Leader for a wideband 10-watt *S*-band solid-state telemetry transmitter. He was Task Leader on the breadboard system test of the Apollo transponder System. He designed and developed frequency multipliers for Apollo block II unified *S*-band equipment and a lumped constant varactor multiplier for the lunar excursion module transceiver. He is coauthor of "A High Gain Severed Circuit Injected Beam Crossed-Field Amplifier," presented at the Fourth International Congress on Microwave Tubes, The Hague, The Netherlands, 1962.