PRINTED-CIRCUIT Ka-BAND MIXER WITH COMPACT FILTER FOR STEP-TUNED LO

by

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ABSTRACT

A miniaturized Ka-band mixer which accepts widely separated LO frequencies has been developed, allowing a wide RF band to be covered in two steps. This restricts the IF bandwidth and eliminates 2x2 spurious mixing products. The mixer includes a unique, compact, LO filter that helps minimize the IF SWR.

INTRODUCTION AND OBJECTIVES

The state of the art for millimeter-wave receivers has been steadily driven by system requirements, including high-sensitivity, wide RF bandwidth, large spurious-free dynamic range, small size, and low production cost. To address these needs, we have developed a group of printed-circuit, front-end components, including RF switches, preselectors, and mixers. The compact Ka-band step-tuned mixer, which is described in this paper, is of special interest.

A wide RF band is covered in discrete steps, offering important advantages to system designers. For N steps, the IF bandwidth can be 1/N times smaller than the RF band, eliminating the 2x2 spurious mixing products associated with octave-band IF amplifiers. Moreover, restricting the IF bandwidth generally allows the IF contribution to the system noise figure to be reduced. To realize these advantages, however, greater demands must be placed on the mixer. The mixer must be impedance-matched at the RF port across a wide, continuous band and at the LO port at two or more discrete frequencies. The mixer design becomes particularly challenging as the spacing between the LO frequencies increases.

In single-balanced mixers, an LO band-pass filter can be a key component in the LO/IF diplexer (1). For a given rejection in the IF band, a conventional band-pass filter requires that more sections be added as the LO bandwidth is increased (2). Because the added sections can increase the size of the mixer, an alternative approach is desirable. The following paragraphs describe a Ka-band mixer with a compact filter which is ideally suited to step-tuned LO's.

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MIXER DESCRIPTION

The mixer is designed to cover the RF band of 26 to 34 GHz, accept LO inputs at 24 and 36 GHz, and provide IF output in the band of 6 to 10 GHz. (A companion mixer covers the RF band of 34 to 40 GHz, providing full coverage of Ka-band with a sub-octave IF.) The key circuit elements of the subject mixer are sketched in Figure 1, and the construction features are shown in Figure 2. The RF circuit includes a conventional WR-28 input port, transformers to low-impedance fin-line, and an RF-matching element. High-cutoff, beam-lead diodes (3) are mounted at the junction of the finline and coplanar line, as shown in Figure 1. The LO and IF connections to the diode mount are in suspended-substrate stripline. The IF passes through a nine-element low-pass filter and a strip-line transition to an SMA connector. The LO enters the mixer through a WR-28 port and a probe transition to stripline (4). A scaling of the existing probe design was necessary to optimize the performance across the LO band of 24 to 36 GHz. The LO feed also includes the unique band-pass filter described on the following pages.

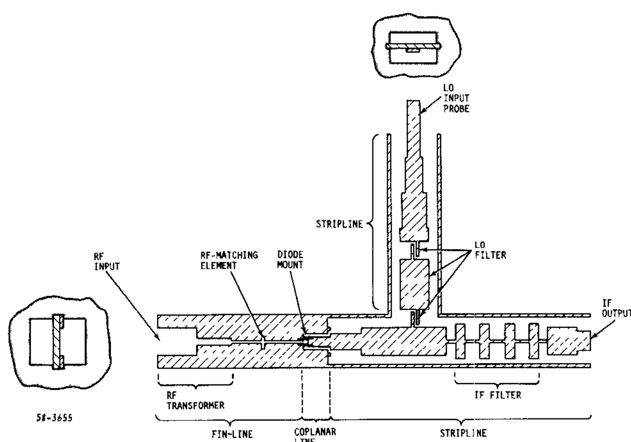

Figure 1. Key Mixer Circuit Elements

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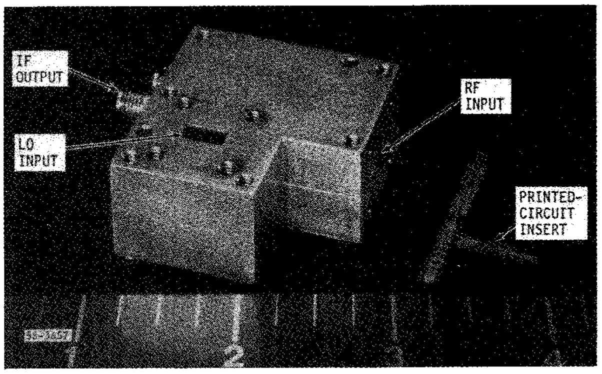

Figure 2. Mixer Housing and Printed-Circuit Board

COMPACT LO FILTER

For the given program requirements, the LO frequencies are 24 and 36 GHz, and the included bandwidth is relatively wide (40 percent). Figure 3 shows two approaches to the design of a printed-circuit, wide-band filter. In the conventional approach illustrated in Figure 3(A), a series of transmission lines are arranged such that adjacent strips are parallel-coupled along a distance of a quarter wavelength. It can be argued that a four-section design should be required for this application (2). In a suspended-stripline embodiment with an equivalent dielectric constant of 1.5, the axial length would be 400 mils, which is long relative to the other mixer elements. Also, the input and output stubs of the conventional filter would each be 80 mils long. If a conventional filter were integrated with a low-pass filter (to form an LO/IF diplexer), the 80-mil stub would appear in shunt with the IF output. The shunt capacitance introduced by this stub would degrade the performance in the upper portion of the IF band. A final argument against the four-section design is that it is overly complex for a step-tuned application. The conventional design provides low loss at all frequencies between the two LO frequencies. Relaxing the specification on loss between the LO frequencies should make it possible to reduce the size and complexity of the filter.

Figure 3(B) shows a new approach to the filter design (5) which requires only two sets of short, coupled lines (with l_1 well below a quarter wavelength at the center of the LO band). At the lower LO frequency (24 GHz), the coupled lines function as lumped capacitors which, in conjunction with the resonator of length l_2, form a single-section bandpass filter. Near and above the upper LO frequency (36 GHz), l_1 approaches a quarter wavelength and and each set of lines functions as a band-pass filter (6). To achieve the desired match in a 50-ohm system, the even- and odd-mode impedances of the coupled lines are chosen such that:

$$(Z_{OE} - Z_{OO})/2 = 50 \qquad (1)$$

While the difference between Z_{OE} and Z_{OO} is fixed, the absolute value of one parameter can be freely chosen, providing control over the stop-band rejection.

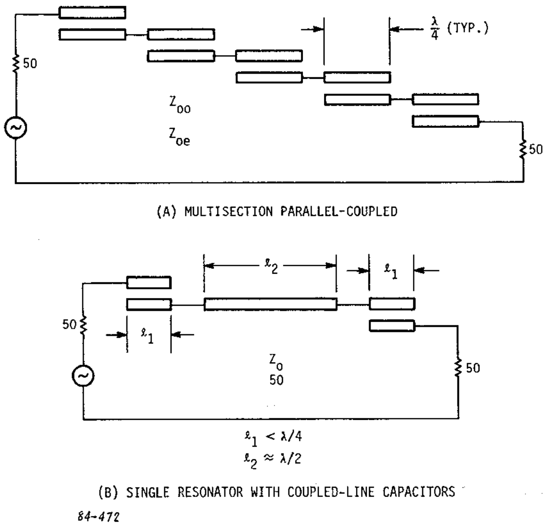

Figure 3. Alternative Wide-Band LO Filters

Figure 4 shows the calculated response of the compact filter. For each of the three examples presented, the parameters W and S (strip width and spacing) were chosen to satisfy equation 1. To maximize the stop-band rejection, l_1 was fixed at 55 mils, the minimum value which provides an adequate guard band below 36 GHz. For each example, the resonator length l_2 was chosen to provide a match at 24 GHz. The curves clearly illustrate the trade-off that can occur between the stop-band rejection and the passband ripple.

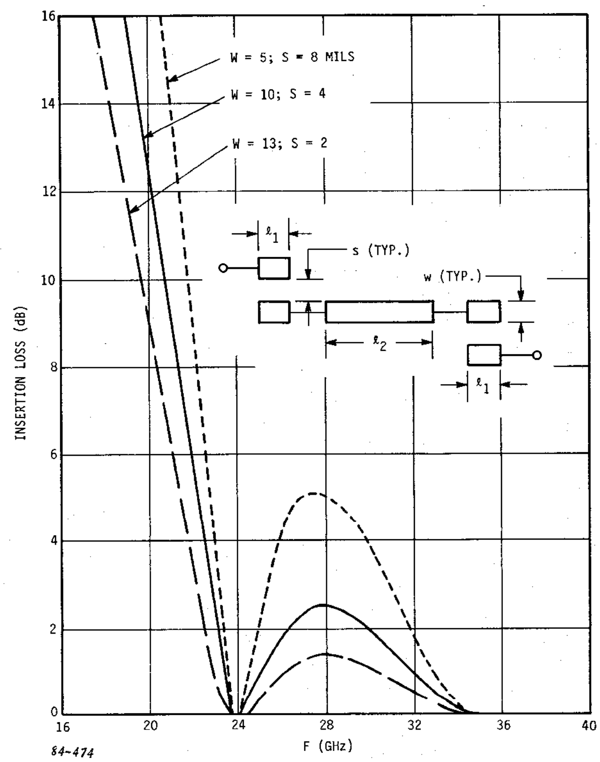

Figure 4. Calculated Response of Compact Filter

To demonstrate the feasibility of the new filter, several breadboard models were fabricated and tested. The filters were printed on 10-mil Duroid 5880 and were suspended in stripline housings with a total groundplane spacing of 62 mils. Two housings were used, each with transitions appropriate to the measurement band. For tests below 26.5 GHz, the filters were embedded between coax transitions. For Ka-band tests, the filters were integrated with waveguide/probe transitions (4). Preliminary tests showed that it was necessary to reduce the physical length of the coupled lines from 55 to 40 mils to compensate for the fringing capacitance.

Figure 5 shows the measured response of the compact filter. As desired, high rejection (25 dB) has been obtained at 18 GHz, and the insertion loss is low (0.5 dB) at 24 and 36 GHz. Additional tests showed that the rejection at 10 GHz was 35 dB. The measurements clearly demonstrate the feasibility of the new approach. The physical length of the new filter ($2l_1 + l_2$ = 230 mils) is almost one-half that required for a conventional, four-section design. When the LO filter design had been completed, the development of the subject mixer began.

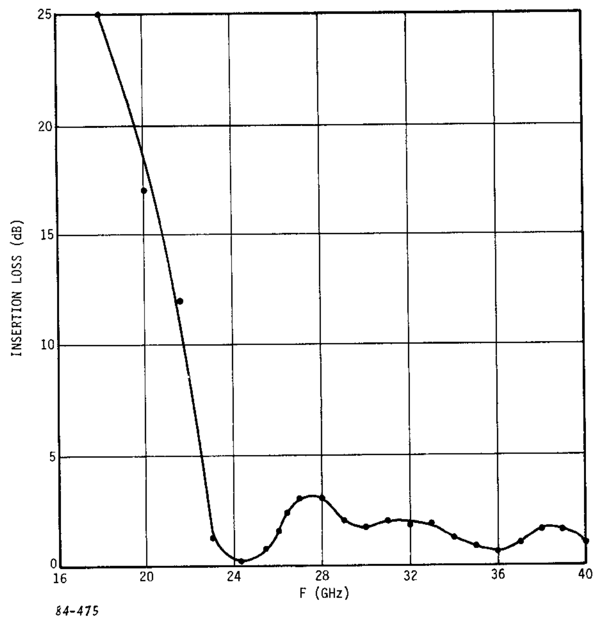

Figure 5. Measured Response of LO Filter (Option C)

MIXER INTEGRATION AND TESTS

The previously described LO filter has been integrated with other printed-circuit elements to form the mixer shown in Figures 1 and 2. After optimizing the match at the RF and LO ports, the measured data of Figure 6 was obtained. Across the RF band of 26.5 to 34 GHz, the conversion loss is 6.6 ±0.9 dB. By step tuning the LO from 24 to 36 GHz, the required suboctave IF-output band of 6 to 10 GHz is obtained. Other measurements include the following:

LO/RF Isolation:	20 dB (minimum)
Excess Noise Ratio:	1
1-dB Compression Point:	+7 dBm
Third-Order Intercept Point:	+14 dBm (minimum)
IF Port SWR:	1.4 (maximum)

The overall volume of the mixer, including waveguide flanges and the SMA connector, is less than 1.5 cubic inches.

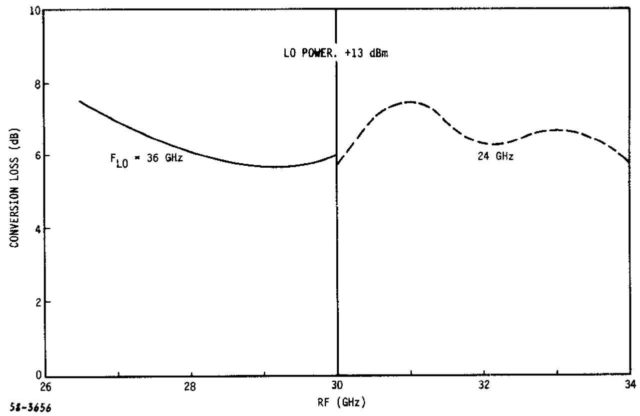

Figure 6. Measured Conversion Loss of Mixer

CONCLUSIONS

A miniaturized Ka-band mixer which accepts widely separated low frequencies has been developed, allowing a wide RF band to be covered in two steps. The mixer is compatible with a low-noise 6 to 10 GHz IF amplifier, eliminating the 2x2 spurious mixing products associated with octave-band IF amplifiers. The mixer includes a unique LO filter which is ideally suited to step-tuned LO's. Relative to a conventional design, the new filter allows the axial length to be halved. Moreover, the compact filter introduces less capacitive loading to the IF line, minimizing the IF SWR.

Because of its small size, wide spurious-free dynamic range, low conversion loss, and printed-circuit economy, the subject mixer is well-suited to a variety of system applications, particularly EW frequency-extension programs.

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