PHASING TYPE IMAGE RECOVERY MIXERS

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Summary

This paper discusses the design of double balanced mixer circuits to effect image rejection, with the potential of low noise performance by recovery of image power. Performance of circuits at S, X and J(Ku) - bands is described.

Introduction

There are two basic forms of mixer circuits to provide image rejection (suppression) properties for single channel operation, either the use of a filter or by phasing techniques provided by two coupled mixers[1]. Both of these should be capable of achieving improved noise figure performance (compared with image matched) if reactive image termination is provided; this leads to the so called image enhancement process. Experience of many workers with phasing mixers, however, has indicated that critical operating conditions and severe performance reproducibility difficulties may be encountered, and in many cases any conversion loss improvement resulting from the image recovery process may not necessarily be reflected in the overall noise figure performance.

It is the intention of this paper to discuss the results of some experimental studies carried out on this subject, aimed at providing a design basis for the production of reproducible, low noise, broadband image rejection mixers for operation at S, X and J(Ku) - band frequencies.

Double Balanced Mixer Configuration

The experimental results obtained with X-band mixers of the MIC type shown in Figure 1 are briefly discussed in this section. The circuit configurations utilise two balanced mixers which employ 3 dB branch arm couplers and commercially available LID mounted GaAs Schottky barrier mixer diodes (i.e. AEI Type No. DC 1301).

Several circuit variants are considered. Briefly these include the application of two matched i.f. amplifiers, one following each mixer before i.f. power combining in the 90° hybrid, and the application of a single i.f. amplifier positioned after the 90° hybrid i.f. power combiner. In each case the effects of different forms of signal power divider are examined: these include the isolated Y junction Wilkinson to isolate the mixers and provide near image matched operation, the T junction to allow interaction of image power between the two mixers[1], and the rat race coupler (with the fourth arm terminated by an open or short circuit) to reflect the generated frequency products, including the image[3].

The experimental results are summarised in Table 1. A single balanced mixer is included for reference purposes. The overall noise figure maintaining image rejection properties >20 dB is the main parameter used for the performance comparison. The conversion loss is in general calculated from the measured i.f. amplifier contribution for a noise temperate ratio of 1.0: evaluation of the conversion loss has confirmed that this assumption may be used with confidence for all circuit configurations except the double amplifier and T-power splitter combination. The diode conversion loss (i.e. referred to the diode terminals) is an estimated value from assumed circuit losses. The r.f. bandwidth is defined by 0.5 dB degradation in overall noise figure performance (for image rejection >20 dB), and the local oscillator power level is for optimum overall noise figure.

Comments

The performance tabled for the twin amplifier system in conjunction with the T signal power splitter is the best observed, but the circuit design is critically dependent on achieving all the correct impedance terminations simultaneously, (r.f., i.f. and modulation products), for accurate image o/c or s/c conditions over the required r.f. bandwidth. Amplitude tracking of the twin i.f. amplifiers is also essential for acceptable image rejection properties. This system can thus result in severe problems of reproducibiltiy and critical operating conditions. In addition, circuits optimised for conversion loss may not necessarily reflect this parameter in the overall noise figure performance. The twin amplifier system can however yield consistent and useful performance results by use of the Y Wilkinson power splitter (or the rat race coupler with a 50 ohm termination on the fourth arm), thus providing mixer operation near image matched conditions. The overall noise figure in this case is simply degraded compared with the single balanced mixer by the additional circuit losses.

An objective of the single i.f. amplifier - T signal power splitter circuit configuration is to provide 50 ohm impedance levels throughout, thus reducing the undesirable effects of the twin amplifier system. The 50 ohm 90° hybrid i.f. power combiner provides a low impedance i.f. termination for the mixers and a constant load impedance for the i.f. amplifier. However, this does imply a high level of l.o. drive for low r.f. and i.f. impedance levels. The system can result in good performance characteristics. The overall noise figure is comparable with the single balanced mixer but with the additional properties of image rejection. Interaction of image power between the two mixers results in a lowering of the diode conversion loss by about 1 dB compared with the image matched situation. This level of image enhancement can also be effected by the signal rat race coupler with the fourth arm terminated in a short or open circuit. However the symmetry of the circuit is no longer ensured by the rat race coupler approach and this can result in inferior image rejection characteristics. A typical noise figure/image rejection frequency response of the form of circuit shown in Figure 1 provides an overall noise figure of about 6.0 dB (60 MHz F_{if} = 2.3 dB) and image suppression >20 dB for 10% r.f. bandwidth. The overall bandwidth is limited by the 3 dB couplers used in the l.o. feed and balanced mixers.

Double Ring Mixer Configuration

A further form of phasing type MIC image rejection/ recovery mixer structure is shown in Figure 2. Following the results outlined in the previous section, the circuit configuration is based on the combined signal T power splitter and single i.f. amplifier system, but with the potential advantage of wider bandwidths and shorter transmission line-lengths provided by the compact ring mixer structure.

The mixers consist of a quad diode with r.f. connections (signal and l.o.) via balanced line feeds. The diode mounting structure is appropriate to the inclusion of LID, beam lead or chip devices, diode pairs being mounted on both sides of the MIC substrate. The circuit example of Figure 2 illustrates the use of a broadband Lange quadrature coupler for a l.o. feed to take advantage of the broadband properties of the ring mixers, and in this case shows the mixers positioned physically close together.

Experimental results of this form of mixer are summarised in Table 2. A single ring mixer is included for reference purposes. The separation 'd' between the mixers is varied between 0 (i.e. as close together as physically possible) and 3/8λ, in 1/8λ steps. The overall results are obtained from swept frequency measurements covering the range of 7 to 12 GHz.

The performance characteristics which may be obtained are illustrated in Figure 3. In this case 'd' = 0 and the diode quad consists of commercially available LID mounted GaAs Schottky barrier diode (AEI Type No. DC 1301). This example indicates an overall noise figure of about 5.0 dB (the spread observed has been 4.8 to 5.2 dB) including an i.f. contibution of 2.0 dB (i.e. 1.7 dB for the 60 MHz amplifier and 0.3 dB loss for the i.f. hybrid). A noise figure performance better than 5.5 dB is maintained for about 20% r.f. bandwidth, with image rejection greater than 20 dB, and i.f. impedance about 50 ohms.

Comments

This type of circuit configuration can result in good and repeatable performance characteristics and behaves favourably, particularly as regards bandwidth and noise figure, compared with its equivalent using the 3 dB coupler form of balanced mixers. Interaction of image power between the two ring mixers results in a lowering of the diode conversion loss approaching 2 dB, compared with the image matched situation. This results in an improvement in overall noise figure of about 1 dB compared with the single ring mixer, after allowing for circuit losses.

The high l.o. power requirement for 'd' = 0 suggests that this diode spacing results in circuit operation near image o/c conditions, with the conclusion that the electrical lengths associated with the quad diode structure prevent image s/c operation even when the mixers are positioned as close together as physically possible. This is confirmed by the 'd' = 1/4λ situation, which reduces the l.o. requirement to satisfy operation near image s/c conditions.

Adjusting 'd' to 1/8λ and 3/8λ suggests that the frequency range of 7 to 12 GHz encompasses both image s/c and o/c conditions near the band edges, thus providing two operating frequencies with their associated low and high l.o. power requirements for minimum noise figure. The observed degradation in noise figure compared with the 'd' = 0 and 1/4λ situation is the result of the image s/c and o/c responses falling outside the overall circuit bandwidth, which is centred about 9.5 GHz. Examination of the mixer i.f. impedance - frequency response clearly identifies the frequencies for image s/c and o/c, and is illustrated in Figure 4 for 'd' = 3/8λ. It is of considerable interest to note the reduction in the i.f. impedance levels with reduced dependency on image termination, by increasing the l.o. power; this has particular relevance to the operation of the double ring mixer configurations near image o/c conditions.

J(Ku) - Band Performance

Similar studies to those carried out at X-band with the double ring mixer configuration are also being carried out in the 12 to 18 GHz frequency range. In this case the quad diode mixers have been constructed using commercially available beam lead GaAs Schottky barrier diodes AEI Type No. DC 1306. The present results are tending to substantiate the experimental evidence obtained at X-band, particularly as regards the effect of varying the spacing between the diode quads. For example an overall noise figure of about 6.0 dB (including an i.f. noise figure contribution of 2.0 dB), for a 10% r.f. bandwidth centred about 17 GHz, has been obtained for a diode spacing of 1/4λ with 40 mW l.o. drive. Comparing this performance with a single ring mixer implies a diode conversion loss of about 3.0 dB (reactive image) and 4.5 dB (matched image) for the double and single ring mixer configurations respectively, when referred to the diode terminals.

System Application

The repeatability and acceptability for application to military environments of the forms of circuits discussed, have been demonstrated by employing these types of image rejection/recovery mixers in production MIC units for military radars in both the S and X frequency bands. For example an S-band version using the double ring mixer configuration utilising silicon LID mounted Schottky barrier diodes (AEI Type No. DC 1506) has provided a 5.0 dB overall noise figure and >20 dB image rejection for a 15% r.f. bandwidth. The l.o. power requirement is 5 mW. At these frequencies it is found that positioning the ring mixers as physically close together as possible represents near image s/c reactive conditions.

Conclusions

The phasing type of mixer configuration described in this paper can be designed to effect improvement in the diode conversion loss, presumably due to the image recovery process resulting from interaction of image power between the two mixers.

The application of twin amplifiers to image recovery designs presents too many parameter variables to optimise simultaneously, resulting in reproducibility problems and critical operating conditions. However, the application of the single amplifier system can realise practical circuits in which the improvement in conversion loss is reflected in the overall performance. The conversion loss and overall noise figure performance enhancement is more pronounced in the case of the quad diode ring mixer configuration than in the 3 dB coupler balanced mixer configuration; this is probably due to the better harmonic and intermodulation product suppression characteristics of the ring mixer. The reduction in conversion loss, referred to the diode terminals, is approaching about 2 dB for the double ring mixer configuration, compared with its single mixer counterpart. This is approaching the theoretically predicted improvement for an image reactive terminated mixer compared with an image matched mixer[2], and would thus suggest that the theoretically predicted improvement in diode conversion loss by reactive image termination may be achieved by the phasing double ring mixer circuit configuration. Further overall noise figure improvement with this type of circuit can only be accomplished by attention to circuit losses and the i.f. amplifier performance. The preferred circuit design of image s/c operation with minimal spacing between the two mixers is difficult to achieve above S-band frequencies due to the electrical lengths associated with the mixer structure. However, the circuits can be operated under image s/c or o/c conditions provided that the low impedance levels (particularly i.f.) are obtained by adjusting the l.o. power.

Finally, both forms of phasing type mixers can be designed and constructed to meet the reproducibility and environmental requirements for production military systems.

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References

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2. Torrey H.C., Whitmer C.A., Crystal Rectifiers, MIT Radiation Laboratory Series (McGraw-Hill, New York, 1948)

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TABLE 1

3 dB Coupler Mixer Configurations Performance Summary

Mixer System	Signal Power Divider	F_0 (dB)	F_{IF} (dB)	L_C (dB)	Diode L_C (dB)	P_{LO} mW	r.f. Bandwidth %
Single Bal.	—	6.0	1.5	4.5	4.1	4	10
Double Bal.-Two i.f.	T	5.3	1.7	3.6	2.8	2	2
"	Y	7.2	2.0	5.2	4.4	20	10
Double Bal.-One i.f.	Y	7.5	2.3	5.2	4.4	20	10
"	T	6.0	2.3	3.7	3.0	20	10
"	Rat Race o/c and s/c	6.0	2.3	3.7	3.0	20	5
"	Rat Race Matched	7.5	2.3	5.2	4.4	20	10

Input Level for 1 dB L_C Compression

≃ +5 dBm for P_{LO} = 20 mW

TABLE 2

Quad Diode Ring Mixer Configurations Performance Summary

Mixer System	'd'	F_0 (dB)	F_{IF} (dB)	L_C (dB)	Diode L_C (dB)	P_{LO} (mW)	F_C (GHz)	r.f. Bandwidth %
Single Ring	—	6.1	1.6	4.5	4.2	12	9.5	50
Double Ring-One i.f.	0	5.0	2.1	2.9	2.5	50	9.0	20
"	1/2λ	5.5	2.0	3.5	3.0	20	9.5	20
"	1/8λ	6.3 6.3	2.0 2.0	4.2 4.2	3.8 3.8	16 50	8.0 11.0	10 —
"	3/8λ	6.5 6.5	2.0 2.0	4.4 4.4	3.8 3.8	16 50	8.0 11.0	10 —

Input Signal Level for 1 dB L_C Compression

≃ +8 dBm for P_{LO} = 20 mW

≃ +15 dBm for P_{LO} = 50 mW

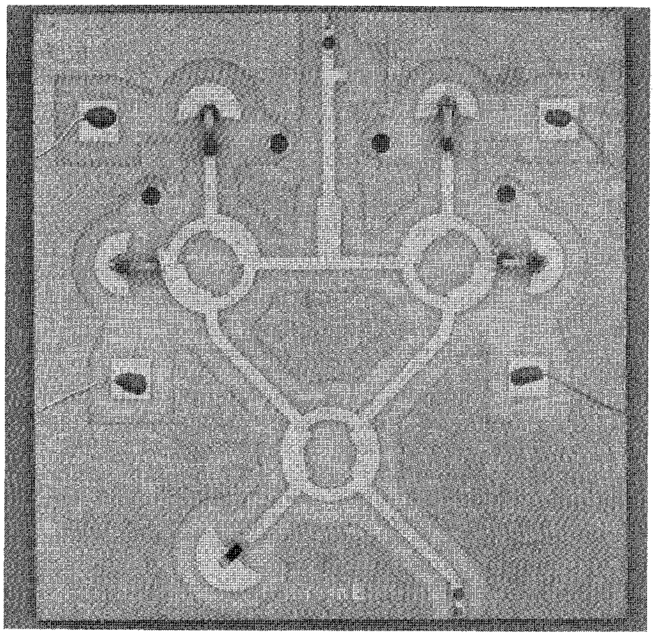

Fig. 1 X-band MIC double balanced image rejection mixer

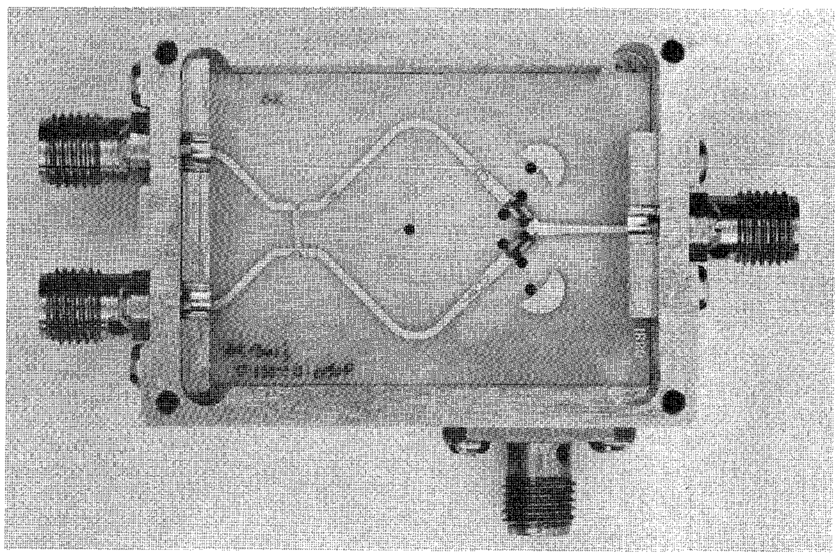

Fig. 2 X-band double ring image rejection mixer

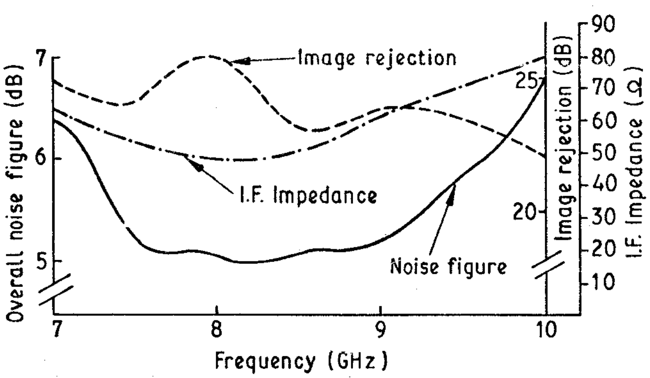

Fig. 3 X-band double ring phasing mixer

Overall noise figure, image rejection, i.f. impedance as a function of frequency

I.F. = 70 MHz		d	= 0
F_{IF} = 2.1 dB (includes 0.3 dB hybrid loss)		P_{LO}	= 60 mW

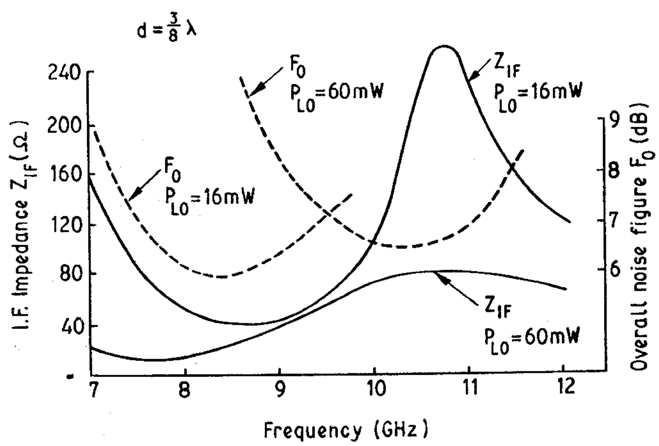

Fig. 4 X-band double ring phasing mixer

I.F. impedance, overall noise figure as a function of frequency