A SUBHARMONICALLY PUMPED FIN-LINE MIXER FOR SATELLITE TV RECEIVER APPLICATIONS

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ABSTRACT

A subharmonically pumped fin-line mixer working at the satellite TV frequency band around 12 GHz has been realized with a simple filter and diplexer configuration. All of the mixing products below and encluding double the LO frequency are suppressed by an RF input high-pass filter, which simultaneously rejects the image frequency band. With non-selected commercially available diodes a conversion loss of 5.5 to 6.2 dB has been measured. The calculated DSB noise figure is between 3.9 dB and 4.6 dB.

Introduction

A subharmonically pumped fin-line Schottky mixer has been realized for an RF band from 11.7 to 12.5 GHz and an IF band from 900 to 1700 MHz. For a subharmonically pumped mixer the signal frequency f_{RF}, local oscillator (LO) frequency f_{LO}, and the intermediate frequency f_{IF} are related by $f_{RF} = 2f_{LO} + f_{IF}$.[1,2] With an IF suitable smaller than the RF, the RF is nearly twice the LO frequency. This fact is used to construct a very simple filter and diplexer configuration.

The following points are most essential for the design of the mixer:

- Low noise and low loss. That means, low cicuit losses and image rejection are required. Fin-line at 12 GHz is a moderately high-Q waveguide and allows direct, low loss coupling to the RF input waveguide coming from the antenna.
- Low costs, because mass production is required. In this point fin-line does not come after microstrip. The housing is not necessarily a precise mechanical component, because the electrical quality of the device is mainly determined by the planar fin-line circuit. To use a subharmonically pumped mixer means to devide the LO frequency by a factor of two. This simplifies the LO.
- Radiation of the LO, its harmonics, and the different mixing frequencies. They habe to be suppressed to a large extend. The RF input waveguide acts as a high-pass filter. If it is well designed, all the frequencies below the RF band are suppressed.
- In order to get full benefit of the given diodes characteristics, a careful theoretical optimization is necessary. To this end a computer programme has been used[1].

Mixer Circuit Design

With the given RF and IF bands the LO frequency results in 5.4 GHz and we habe a frequency sheme as shown in Fig. 1. Double the LO frequency at 10.8 GHz and the side-

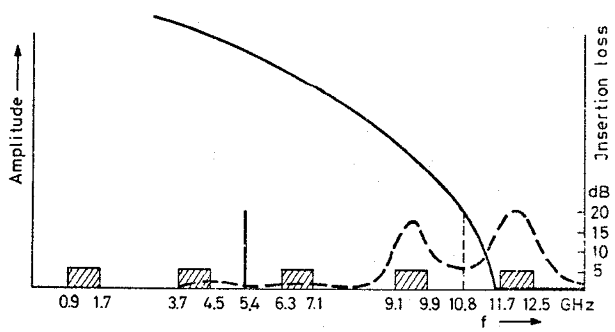

Fig. 1 Frequency sheme of the mixer, insertion loss of the high-pass-filter at the RF input and the microstrip-to-fin-line transition

bands of the LO fundamental frequency do only come up when the diodes characteristics differ. Because of the requirements listed in the introduction, we have to provide for all of the frequencies ≤ 10.8 GHz to be suppressed by the RF input waveguide, and for the RF band to be so loaded at the diodes, that the mixer is as good as possible matched to the RF generator impedance. Let us first consider the fin-line structure.

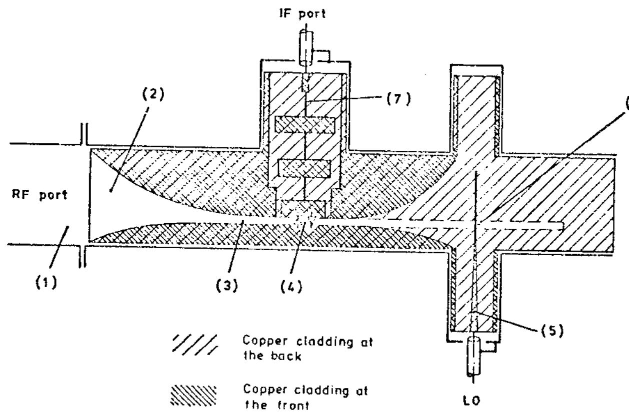

Fig. 2 Layout of the planar fin-line printed board

Fig. 2 shows the printed board of the planar mixer fin-line structure, which has to be thought inserted parallel to the E-plane of a standard X-band rectanglar waveguide. The cutoff frequency of the waveguide without fins is $f_C(WG) = 6.56$ GHz. This means, that the LO and IF powers do not propagate on the RF input waveguide (1). However, because to insert fins into a waveguide means to decrease its cutoff frequency $f_C(Fl)$[4], $f_C(Fl)$ can be chosen to $f_{IF} < f_C(Fl) < f_{LO}, f_{RF}$, so that the LO and RF powers but not the IF power propagate on the fin-line. The RF frequency input reflects the LO power. The RF input power gets by way of a waveguide-to-fin-line transition (2) and a fin-line (3) to the Schottky diodes (4).

The LO power gets after passing a microstrip (5) to a microstrip-to-fin-line transition (6), which operates similar to a known microstrip-to-slot-line transition[5]. Normally, in order to match that transition, the open-circuited microstrip stub and the shorted slot extend about one-quarter of a wavelength beyond the crossing point. In this case the transition transmits the LO frequency without considerable loss and reflects double the LO frequency and adjacent frequencies. Measurements have but shown, that the stop band is too small to reflect both the RF and image frequency bands, which would be essential for a low noise mixer. For improvement the transition has been made unsymmetric, i.e., the stubs have been made of different lengths. Then the transition has an insertion loss as shown by the dashed curve in Fig. 1. The loss at the LO frequency is about 0.8 dB, for the RF and image frequencies it exceeds 10 dB but is only about 8 dB for

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10.8 GHz. By properly choosing the fin-line impedance as well as the distance between the Schottky diodes and the transition, the real and imaginary part of the signal input impedance can be matched. The IF is extracted by way of a conventional microstrip low-pass filter (7).

RF Input High-Pass Filter

The operating sheme described so far suffers from two disadvantages. Firstly, without regard to reactances, which the mixer produces itself, all of the mixing products above 6.56 GHz are ohmic terminated by the RF input. Secondly, all of these mixing frequencies will more or less be radiated by the antenna. One can overcome these problems by a high pass filter at the RF input. Its insertion loss is shown by the solid curve in Fig. 1. The high-pass filter is dimensioned so that its cutoff frequency is at 11.2 GHz. It is constructed of a broadside-tapered waveguide section[6], as shown in Fig. 3.

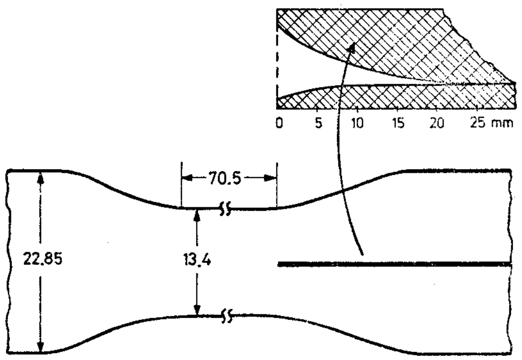

Fig. 3 Layout of the high-pass filter broadside-tapered waveguide section

The right hand side edge of the homogeneous part of the high-pass filter is so positioned that it is flush with the starting point of the fin-line taper. The width of the homogeneous part is 13.4 mm. This construction is advantageous in that sense that the different mixing products are reactively terminated as close to the diodes as possible. Furthermore, the overall length of the mixer is minimized.

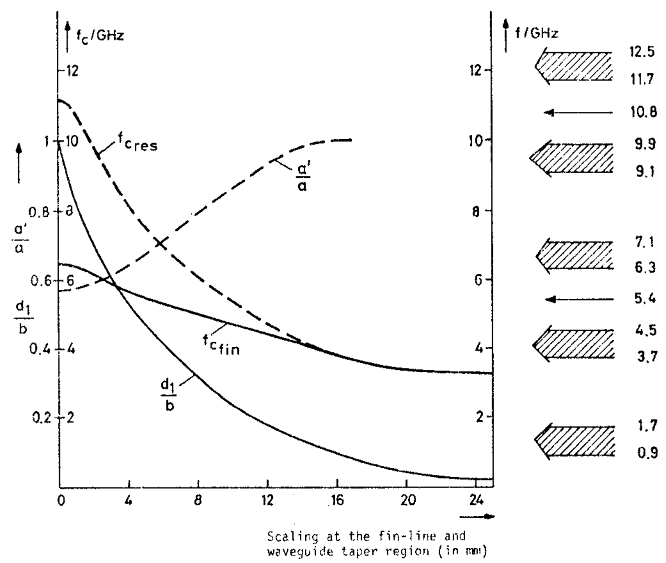

Fig. 4 Profile of the fin-line taper (d_1/b) and of the high-pass filter right hand side taper (a'/a). Cutoff frequency profile of the fin-line taper ($f_{c_{fin}}$) and the resulting profile for both tapers together ($f_{c_{res}}$)

The length of the homogeneous part of the high-pass filter is determined by the required insertion loss at the highest frequency within the stop band, that is at 10.8 GHz, and by the width of the transition range between the stop band and the pass band. With an insertion loss of 20 dB at 10.8 GHz and a transition range of about 770 MHz the length of the homogeneous part results in 70.5 mm. This length can be considerably shorted when the required loss is reduced. Anyway, for frequencies lower than 10.8 GHz the insertion loss increases rapidly. Following[6], the contours of the waveguide tapers have been dimensioned so that the insertion loss at the RF band is less than 0.2 dB. For the right hand side taper it has been considered that it overlaps with the fin-line taper.

Fig. 4 shows the profiles of the fin-line taper (d_1/b, with d_1 the slot width and be the height of an X-band waveguide) and of the high-pass filter right hand side taper (a'/a, with a the width of an X-band waveguide and a' the reduced width). Without the high-pass filter, along the fin-line taper one has a cutoff frequency profile as denoted by $f_{c_{fin}}$. Adding the high-pass filter means to increase the cutoff frequencies at the left part of the tapers, as shown by the curve denoted by $f_{c_{res}}$. All of the frequencies between about 4 GHz and 10.8 GHz are reflected closer to the diodes.

Results

For a theoretical optimization of the mixer performance with a computer programme[1] the loads at the different LO harmonics and their sidebands as well as the diodes equivalent networks must be known. As to the diodes, two nonselected HP 2082-2716 beam lead Schottky diodes have been used and their characteristics can be taken from the manifactures catalog. We first assumed the diodes to be equal and at room temperature. The different loads for the harmonics and the sidebands have been measured as they appear at the diodes.

After some circles of measuring and calculating, an RF generator admittance of 7.7 mS, that means a slotwidth of about 0.6 mm, and an IF load admittance of 10 mS (thus we have a transforming IF low-pass filter) turned out as a good compromise between mixer performance and a realizable device. This is explained by Figs. 5, 6, and 7.

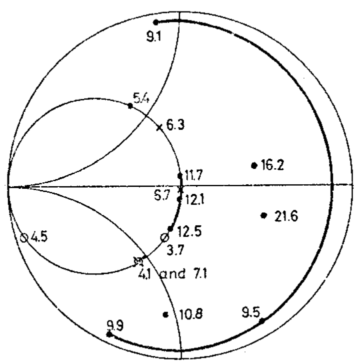

Fig. 5 Measured load admittances for the most important mixing products at the diodes (notation in GHz), normalized to 7.7 mS

Fig. 5 shows the measured admittances, the most important mixing products at the diodes are loaded with. They are normalized to 7.7 mS. Fig.6 depicts the corresponding calculated results for the conversion loss L, the DSB noise figure F, and the optimum conversion loss L_{opt} and noise figure F_{opt}, which hold for the case when the mixer is matched by the optimum RF generator and IF load admittance for minimum loss. The figure holds for an RF of 12.1 GHz. The optimum curves show distinct minima of L_{opt} = 4.3 dB and F_{opt} = 2.9 dB at rather low LO power levels. Simultaneously, the levels of the corresponding optimum admittances (Fig. 7) are very low. With the admittances chosen, the minimum values for L and F are at

6 dB and 4.1 dB, respectively. Even lower admittances would mean too large a fin-line slotwidth, the diodes could not be mounted, the microstrip-to-fin-line transition as well as the IF output could not be matched.

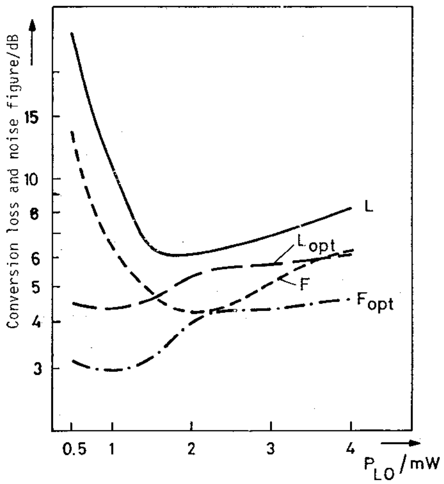

Fig. 6
Calculated conversion loss L, DSB noise figure F, and the optimized values L_{opt} and F_{opt}, f_{RF} = 12.1 GHz

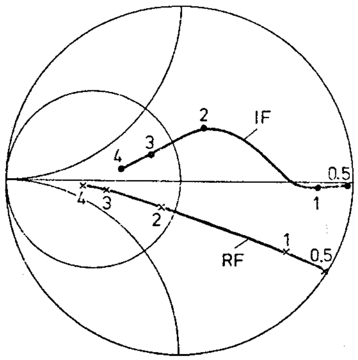

Fig. 7
Optimum RF generator and IF load admittances for minimum loss (notation in mW), normalized to 7.7 mS, f_{RF} = 12.1 GHz

Following Fig. 6, an LO power level of 2 mW is a good compromise between minimum loss and noise figure. As depicted in Fig. 8, the conversion loss and noise figure increase gradually with the RF. A detailed practical examination of the theoretical results at the time is only possible for the conversion loss. The measured points for the loss are even a little bit better than the calculated ones, which could be a sign for the diodes to be better than statet by the manufacturer. Calculations have shown, that the measured and calculated results agree much better, when simply the series resistances are reduced from 5 Ω to 4 Ω. Because the image frequency band is mainly loaded reactively, the SSB noise figure should not be much higher than calculated. This presumption is confirmed by the fact, that for IF frequencies below 500 MHz, where our noise figure test set works well, the SSB noise figures encluding an IF amplifier noise figure of 2 dB are near 5 dB.

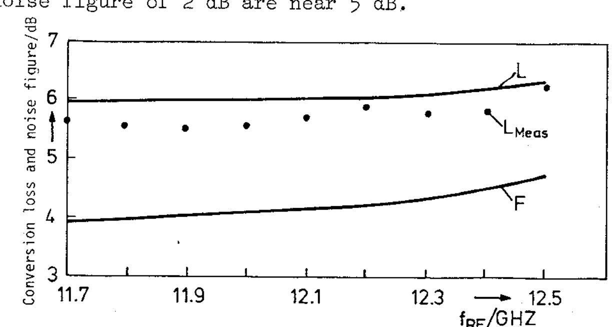

Fig. 8 Calculated mixer conversion loss L and DSB noise figure F for an LO power of 2 mW. The points hold for the measured conversion loss.

Finally, some attention has been drawn to the case when the diodes have different characteristics. In general, differing diode characteristics cause a DC current, produce even LO harmonics, give rise to mixing products adjacent to the odd LO harmonics, and change the mixer loss and noise figure. The following considerations hold for an RF of 12.1 GHz, an LO power of 2 mW, and a DC load of 50 Ω. Table 1 gives an survey of the DC currents and different LO harmonics coming up when we have different saturation currents 10^{-12} and 10^{-13} A (symbol ΔI_S), series resistances 5 and 4 Ω (ΔR_b), barrier capacitances at zero voltage 0.08 and 0.06 pF (ΔC_o), and when all these three parameters differ at the same time (Δ). The table shows that different saturation currents have the greatest influence on the mixer performance.

	DC current/µA	Relative true powers at the loads of the LO harmonics compared to the LO power of 2mW/dB 0GHz	10.8GHz	16.2GHz	21.6GHz
ΔI_s	149.4	-33	-36	-22	-36
ΔR_b	2.9	-67	-68	-20	-65
ΔC_o	3.9	-64	-61	-20	-58
Δ	138.6 (The DC currents in parts cancel)	-33	-37	-22	-37
No differences	0	-∞	-∞	-20	-∞

Table 1 Calculated DC currents and relative LO harmonic powers for differing diodes characteristics.

After all, the even LO harmonic are 36 dB below the LO power and we have a DC current of about 150 µA. Simultaneously, the mixing products at 4.1 and 6.7 GHz are suppressed by about 25 dB compared to the IF. Indeed, that the diodes used are not identical is shown by the fact, that a DC current of 80 µA and a harmonic power of -60 dBm at 10.8 GHz could be measured at the RF input, the last in spite of the high-pass filter. Mixing products with lower frequencies were below the measuring range of the spectrum analyser.

Conclusions

Fin-line seems to be well suited for application in satellite TV receivers. On the other hand, it is well known from the theory, that subharmonically pumped mixers have somewhat higher losses than single ended or single balanced mixers. However, the results presented here could be improved by better diodes. The design should be applicable up to the mm-frequency range.

Acknowledgement

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