II-2. INSTABILITIES IN VARACTOR MULTIPLIERS

D. B. Leeson

Applied Technology, Inc., Palo Alto, California

Introduction. Operating instability and spurious oscillations are principal factors preventing widespread success with varactor frequency multipliers. This paper outlines a theory of multiplier instability which relates universal characteristics of non-linear resonant circuits to the observed behavior of varactor multipliers and multiplier chains. Design criteria and test methods for stable multipliers are developed; their validity is supported by data on multipliers shown to be stable over wide variations in environment, drive level and load.

Design and testing of a varactor frequency multiplier at a single power level and load impedance does not guarantee unconditional stability. In order to be useful, a multiplier must be sufficiently insensitive to interface impedance and power variations to allow spurious-free operation without constant attention.

Sources of Instability. Early theoretical analyses and following works based on them have, for the most part, ignored the problem of instabilities. It is now possible to pinpoint at least the following four sources of multiplier instability:

1) Parametric subharmonic oscillations
2) Thermal relaxation oscillations
3) Bias oscillations in a single stage
4) Whole chain oscillations due to higher order resonances

Subharmonic or parametric oscillations require the presence of one or more supporting resonances. The phenomenon of subharmonic oscillations in the presence of a suitable multiply resonant structure is well-known. The range of resonances which can support oscillations of this type is limited to a few frequencies related directly to the strongly pumped multiplier frequencies (input, idlers, and output). It has generally proved possible to avoid resonances which could support oscillations of this type, since the number of critical frequencies is small.

Thermal relaxation oscillations have been suspected in cases where spurious sideband frequencies correspond closely to estimated varactor thermal time constants. This type of oscillation can occur in circuits which are overly sensitive to varactor parameters. The use of open circuit self-bias has resulted in low frequency oscillations which result from the temperature-sensitive reverse leakage of the diode. Low impedance biasing and conservative power rating avoid thermal oscillations.

The use of low impedance bias circuitry also avoids bias-supply oscillations caused by r-f induced negative resistance[1]. Application of zener diodes has proven successful in a number of cases, and the relationship of bias supply characteristics to the stability of a single multiplier stage has been established in practice as well as in theory.

In addition to parametric and bias supply oscillations, whole-chain spurious oscillations are frequently observed in frequency multiplier chains. These oscillations are usually sensitive to interface variations such as line length or power level changes, and severely limit the usefulness of a varactor multiplier.

Relationship of Passband Discontinuities and Spurious Oscillations. Swept frequency measurements on multiplier chains have shown extremely good correlation between spurious oscillations and step discontinuities in the multiplier chain passband. These discontinuities are very sensitive to varactor temperature and to source and load characteristics. While discontinuous behavior has been measured independently and reported in the literature[2], it is believed that the following derivation sheds additional light on this behavior[3].

One mechanism by which these discontinuities contribute to whole-chain oscillations is as follows:

a) Any impedance or amplitude variation at the first stage of a multiplier chain causes phase-modulation of the signal.

b) The modulation index is increased by the multiplication ratio of the chain.

c) Step discontinuities in the output passband are a high gain phase-modulation to amplitude-modulation conversion process.

d) Amplitude variations so caused will propagate back through the chain, resulting in level changes in the first stage, thus closing the loop for oscillation.

e) The frequency of oscillations of this type will be related to the propagation time through the chain.

Sources of Passband Discontinuities. The step discontinuities behavior can be explained in terms of well-known non-linear phenomena described by Duffings equation[4]. Discontinuous jumps are characteristic of lightly loaded resonances of a non-linear circuit, arising as follows:

a) All of the higher order modes of the multiplier circuit and its interconnections are in general coupled to the varactor(s) and these modes are lightly loaded.

b) When the diode is swung into the high capacity region by the fundamental signal, very high order harmonics can sample large capacity variations with a very small signal level; thus, the higher order modes are strongly non-linear.

c) These strongly non-linear lightly loaded higher order modes will display step discontinuous behavior; the number of such modes depends upon circuit volume and line lengths.

d) Step discontinuities at higher harmonics will be coupled back to the operating frequencies through the non-linearity of the varactor, and will appear on the output passband.

Design Criteria for Avoiding Discontinuities. Spurious oscillations due to this source can be prevented by isolating the varactor from the higher order modes of the embedding structure. This implies the use of multi-section input and output filters with high outband rejection extending many octaves above and below the passband; these filters must be located physically as close to the varactor as possible to reduce the number of modes in the line length between the diode and the filter. A minimum physical volume is necessary to implement these requirements, and integration of the diode into the output filter avoids unnecessary line length.

This hypothesis was tested by designing and constructing a X96 multiplier chain with output at X band. No isolators or circulators were used. The diodes were used. The diodes were located integrally with the filters, and two-and-three section filters were used. A number of these chains have been produced, and all exhibit a smooth bandpass and complete freedom from spurious oscillations over a wide range of conditions as listed here:

1) Temperature varied from 0° F to 130° F.

2) Input power to the chain varied from above nominal smoothly down to zero.

3) Supply voltage of the transistor driver varied from above nominal smoothly down to zero.

4) Arbitrary line-length variations at input, output, and interstages.

5) Mating into a chain of individual multipliers tuned separately in a standard test set-up.

6) Addition of a narrow-band filter or circulator in the output line remote from the multicoupler.

7) Load VSWR of 3:1 for all phase angles.

Because of the importance of passband characteristics, swept frequency measurements and their interpretation are an essential part of multiplier design and characterization. The establishment of higher order modes at the output of a chain by using an output frequency bandpass filter separated from the chain output by a sliding line has proved to be a powerful test of multiplier and driver stability.

The accompanying photographs show reflection (upper trace) and passband (lower trace) for a X12 multiplier from 1 to 12 Gc. This unit has multiple section input and output filters; the diode is integral with the output filter. The sweep is unblanked (bidirectional sweep) to show hysteresis. Figure 1 shows the passband and reflection for the multiplier as normally adjusted. Figure 2 shows step discontinuities and hysteresis present in both input reflection and transmission passband - the multiplier was purposely misadjusted to show this effect.

Figure 3 shows the smooth passband characteristics associated with a spurious-free multiplier with input varied in 1 db steps over a 15 db range (no adjustments). The multiplier output is free of spurious oscillations under the smooth passband conditions shown - this multiplier has been observed to be stable while operating into a 60:1 VSWR over all phase angles.

Figure 1 - Input reflection (upper trace) and output passband (lower trace) for bidirectional swept frequency input to 12 Gc multiplier

Figure 2 - Step discontinuous behavior with hysteresis - this condition will result in spurious oscillations.

1) McDade, J. D., "Jump Phenomena in Varactor Diode Circuits" DOFL TR-1008, January 1962.

2) Taub, J. J. et al (AIL), "Frequency Multiplier" QPR 2, pg. 20, Contract DA36-039-AMC-03196(E) USASRDL, 31 December 1963.

3) Leeson, D. B., Remarks, Evening Panel Discussion, 1965 Solid State Circuits Conference.

4) Cuningham, W. J., "Non-Linear Analysis," McGraw-Hill, 1958 pp. 171 ff.

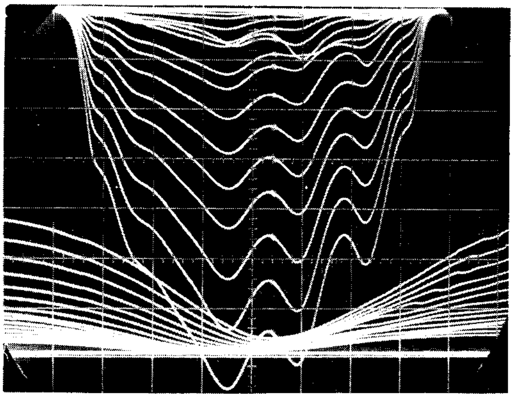

Figure 3 - Passband for input power variations in 1 db steps showing operating stability of multiplier designed to avoid spurious oscillations.