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Study of the single frame parametric generator (SFPG)

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Abstract: The parametric generators (PG-s) are high-efficient frequency dividers, that are often used in frequency mixing and modulation. The application range of PG-s is very large, e.g. in the quantum phase devices that are capable of receiving signals of lower intensity than noise, and storing of information for both phase information or quantization of stable phase states. PG-s are also present in many other applications.

I. Introduction

Parametric generation is known from the years 30s of the last century but is still researched today because of various application in different branches of science and technology. The PG-s usually exhibit high stability of frequency and can involve several mechanisms to stabilize the voltage of the generators.

We study the self-resonating systems with parametric responses:

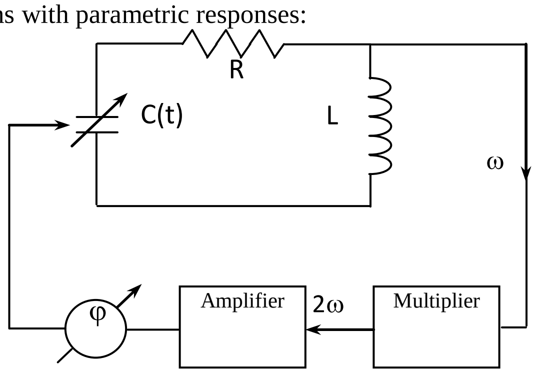

Fig. 1 Schematic diagram of parametric responses [1]

In this scheme the non-linear character of a capacitor C that changes the depth of modulated parameter m, is a cause limiting the amplitude (besides the other factors such as frequency shift ξ, non-linear impedances in the diodes...), the non-linear electric flux cannot generate the limitation of amplitude (as it cannot change the modulation coefficient) but it alters the shift of frequency. The property of this self-resonance system is the introduction of the 2ω frequency in the frame, similar as an introduction of the negative impedance (recurrence). The system satisfies the following criteria on phase and amplitude [1,3]:

- Amplitude

$$\mathrm{A} = \frac{\mathrm{P}}{2\theta \pm \frac{\mathrm{m}}{2}} \tag{1}$$

- Phase: Strong resonance

$$\varphi = -\pi/4 \Rightarrow \mathrm{A} = \frac{\mathrm{P}}{2\theta - \frac{\mathrm{m}}{2}} \tag{2}$$

- Phase: Weak resonance

$$\varphi = \pi/4 \Rightarrow \mathrm{A} = \frac{\mathrm{P}}{2\theta + \frac{\mathrm{m}}{2}} \tag{3}$$

In case of strong resonances (with recurrences): $A = \dfrac{P}{2\theta - \frac{m}{2}}$ (4)

$$\Rightarrow -\frac{m}{2}+2\theta=\frac{R}{\omega L}-\frac{m}{2}=\frac{1}{\omega L}\left(R-\frac{m}{2}\omega L\right)$$
$$\Rightarrow R_{-}=\frac{m}{2}\omega L=\frac{m}{2\omega C_0} \quad (5)$$

With $\theta = R/(2\omega L)$ as an element which includes loss coefficient, here the pump is a resonance of amplitude *a* transported from a response circuit, with phase inversion for phase selection of highest resonance. The amplifying circuit acts as energy transporter from dc-source to the system by amplifying the response signals of frequency 2ω. When the self-kick conditions are satisfied:

$$R < \frac{m}{2}\omega L = \frac{m}{2\omega C_0} = R_{-} \quad (6)$$

There will appear in the system the self-starting resonances. The modulation coefficient m depends on *a*. From (6) we can observe the threshold of m, this means that *a* cannot be smaller than some particular value.

In general, the self-resonance parametric generator is a system which operates in a fixed operating regime: the resonance appears only when pumping amplitude is greater than a certain minimum value. There is a problem that arises: can we have a very large amplifying coefficient? Although the threshold can be manipulated to be as small as needed but it has to exist and cannot be set to zero (there is always a positive pump amplitude needed to start the system). In a soft regime there will be no need of this kick-off threshold. Therefore we have the condition for a self-resonance system as:

$m(a)\rangle \frac{2R}{\omega L}$ or $\frac{\Delta C}{C}\rangle \frac{1}{Q}$ with $Q=\frac{\omega L}{R}$ is the quality coefficient of the frame, $a > a_0$

Here the energy needed to feed the resonance circuit comes from the dc-source and amplifying level. The process of establishing the stop amplitude follows from the non-linearity of the system: it can be caused by non-linearity of a resistance R, or other non-linear elements of the response circuit (note that the amplifying level works in a saturated regime, and a decrease of amplitude depends on the increase of the amplitude of input signals, in other words the coefficient of parametric generation decreases when amplitude of frequency ω of response circuit increases), or by combination of these factors. Therefore we need to select a suitable degree of non-linearity of response circuit.

The angle α depends on damping coefficient, when δ increases than α also increases. From Fig. 2 we see that the parametric resonance can easily start when $N=\frac{2\omega_0}{p}=1$ and when δ is small. As for, $m = m_1$ the resonance starts in the regions with N = 1, 2, 3,... When N = 4 the resonance cannot be started. It is difficult to observe the region with N = 2 in experiment as except a frequency ω_0 we still have a pumping frequency p. The width of parametric start for N = 1 is larger than that of N = 2. This means that the frequency shift between ω_0 and $\frac{p}{2}$ in the first case is larger than that in the second case.

The regions of kick-off parameters according to theoretical calculation [1,2]:

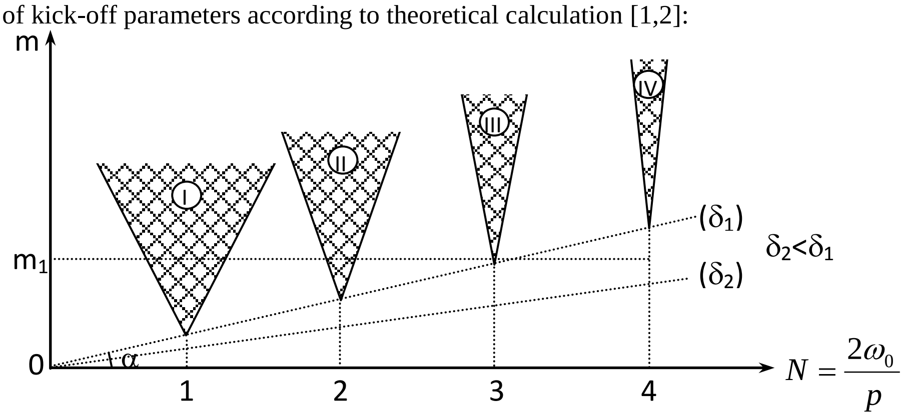

Fig. 2 Resonance regions of parametric system when δ ≠ 0

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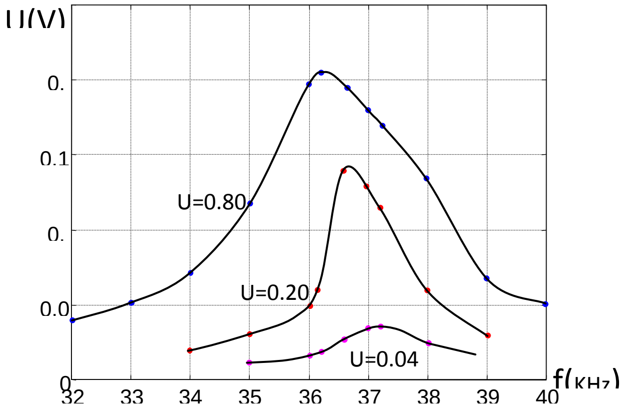
II. Test Experiment

For the investigation of characteristics of parametric resonance of a frame the input signals are 0.8, 0.2 và 0.044 V. When the amplitude of the signal changes, the capacitance exhibits certain impacts therefore the resonance frequency shifts to left. After the resonance test of a frame we study the regions of parametric generations corresponding to different values of the coefficient N, modulating the pumping frequency to match the resonance frequency of the frame.

a) The single frame parametric generator



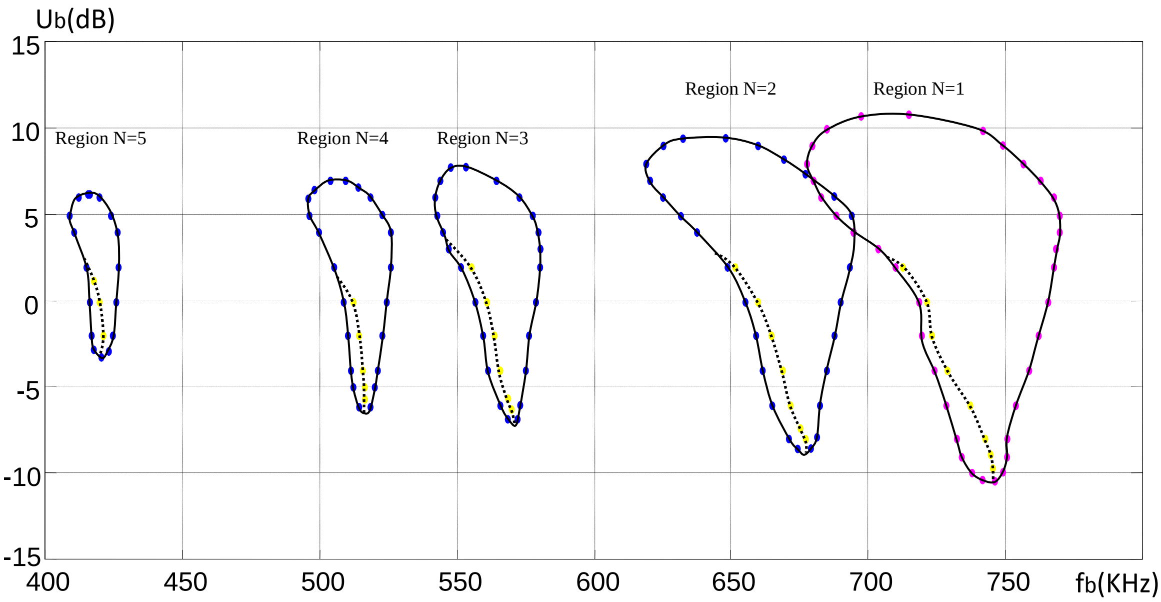
b) Characteristic resonances of a frame

Fig. 3 The characterization of resonance of a frame

Region	C(pF)	Resonance frequency f_{10}(KHz)	Resonance width (KHz)	Quality factor
1	100	373.0	8.6	39.3
2	147	338.6	6.1	55.5
3	257	285.0	4.0	71.4
4	335	259.8	3.6	72.1
5	567	211.4	2.6	81.0

Table 1. Regions of parametric generations with different resonance frequencies

Fig. 4 Regions of parametric generations with different resonance frequencies



Therefore when changing C we can manipulate the resonance widths and thresholds (caused m is changing) and the maximum of generated frequency. Greater is the resonance frequency, larger is the generated region and smaller is the threshold. The regions with lower frequencies are narrowed as the impedance of the capacitor increases more than that of the induction coil. The experiment shows that when C_1 increases the generation width decreases but the quality factor increases. One can see that for large C ($C > C_0$) the role of the diode is small, it does not affect the quality factor Q. When the generation width is decreased, the pumping threshold U_b increases because when C_1 increases the coefficient of the parametric generation decreases ($m = \frac{\Delta C}{C + C_0}$) than it is difficult to generate. If the diode is replaced by a ceramic capacitance C_0=200 pF than when C increases only Q decreases (largest Q when $|\omega L| = \left|\frac{1}{\omega C_\Sigma}\right|$, with $C_\Sigma = C_1 + C_0$).

III. Discussion

The investigation of the range of the parametric generator shows that the experimental results agree quite well with the theoretical ones. When the coefficient N increases, the generator range decreases but the regions with high N show many interesting properties that require further studies to open the possibility of application of parametric generation, including frequency modulation and division when N changes and this is very profitable for the electronic techniques.

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