# **CAPACITIVE FLUX COMPRESSION GENERATOR**

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**Abstract** Conventional Flux Compression Generators (FCG's) are used to generate high power DC pulses. A new kind of (FCG's) with series capacitance called Capacitive Flux Compression Generator (CFCG) will be introduced and explained in this paper. This new kind is used to generate modulated high power pulses. There are some problems to establish a capacitance in high power and high frequency applications. In the present paper several practical methods will be addresed to make capacitance in high power and high frequency applications.

Key Words Flux Compression Generator, High Power Sources, High Frequency Sources

چکیده مولد های شار فشرده معمولی برای تولید پالسهای توان زیاد DC ساخته شده و مورد استفاده قرار می گیرند. نوع جدیدی از این مولدها تحت عنوان مولد شار فشرده خازنی در این مقاله معرفی می شود که توانایی ایجاد پالس های توان زیاد در فرکانس دمای بالا (در حد چند ده مگا هرتز) را دارد. برای این کار از یک خازن سری که با سلف مولد رزنانس می کند، مورد استفاده قرار می گیرد. برای ایجاد این خازن سری باید از روشهای خاصی استفاده کرد که خاصیت خازنی در جریان و فرکانس های بالا حفظ شود.

## **1. INTRODUCTION**

FCG's are used extensively in several applications especially when high current pulses are needed in applications such as electromagnetic launchers, welding metal forming, geological mapping, and radar. FCG's can be considered as linear electrical generators. Electromagnetic energy is stored in an inductor with an initial "seed current". Mechanical motion causes a decrease in the system inductance at such a rapid rate that the flux interlinked with it has no time to diffuse out and, therefore remains practically constant. FCG's have been the subject of many studies [1-20]. The principal ideas on FCG's and its applications following the interesting work of Kapitza [1] have been presented in [2]-[12]. [13] Addressed some problems regarding microsecond pulsed high power generators. [14] Introduce a FCG code with special interesting capabilities.

Proximity and skin effects have been explained

briefly in [15]. Some possible mechanisms of losses have been developed in [16]-[17]. S. I. Shkuratov [18] focused on the development of generators using kinetic energy of ferromagnetic projectiles. [19]-[21], explained several concepts for production of initial energy to power magnetic FCG's, and finally [22]-[24] present some special noval FCG's. Capacitive flux compression generator (CFCG) is a devise to generate high frequency modulated high power pulses. Its function is the subject of a limited number of researches [25-26]. Fundamentals of high explosives, CFCG principles with an emphasis on the helical generator, as well as limiting physical mechanisms will be addressed in this paper.

## 2. ONE DIMENSIONAL MODELING

Figure 1 shows the circuit model for CFCG. It is supposed that R and C are constants and L(t) is a

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Figure 1. The circuit model for CFCG.



Figure 2. L(t) as a function of time.

variable as shown in Figure 2. The differential equation describing the system is given as

$$\frac{\mathrm{d}}{\mathrm{dt}}[\mathrm{Li}] + \mathrm{Ri} + \frac{1}{\mathrm{C}}\int \mathrm{i}\mathrm{dt} = 0 \tag{1}$$

in which

$$L = L_0 - \frac{L_0 - L_1}{T}t = L_0 - at$$
 (2)

From 1 one has

$$L\frac{di}{dt} + i\frac{dL}{dt} + Ri + \frac{1}{C}\int idt = 0$$
(3)

or

$$L\frac{di}{dt} + (R-a)i + \frac{1}{C}\int idt = 0$$
(4)

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Differentiating 4 yields to

$$L\frac{d^{2}i}{dt^{2}} + \frac{di}{dt}\frac{dL}{dt} + (R-a)\frac{di}{dt} + \frac{i}{C} = 0$$
 (5)

or

$$L\frac{d^{2}i}{dt^{2}} + (R - 2a)\frac{di}{dt} + \frac{i}{C} = 0$$
 (6)

The initial current and voltage stored in the inductor and capacitor are  $i(0) = I_0$  and  $v_c(0) = 0$ . So one has

$$v_{c}(0) + L(0)i'(0) + Ri(0) + i(0)L'(0) = 0$$
 (7)

or

$$i'(0) = \frac{(a-R)I_0}{L_0}$$
(8)

Defining

$$p(t) = \exp\left[\int_{0}^{t} \frac{R - 2a}{L_{0} - a\tau} d\tau\right] = (L_{0} - at)^{2 - \frac{R}{a}}$$
(9)

$$s(t) = \frac{p(t)}{L_0 - at} = (L_0 - at)^{1 - \frac{R}{a}}$$
(10)

6 can be written as

$$\frac{\mathrm{d}}{\mathrm{dt}} \left[ p(t) \frac{\mathrm{di}}{\mathrm{dt}} \right] + \frac{\mathbf{s}(t)}{\mathrm{C}} \mathbf{i} = 0 \tag{11}$$

It can be shown that 11 is self adjoint. So it has a unique solution as

$$i(t) = \sum_{n=0}^{\infty} a_n t^{r+n}$$
 (12)

where  $a_n$  and r are constants to be determined. Setting 12 in 6 and choosing r = 0 gets to

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$$(L_{0} - at)\sum_{n=2}^{\infty} a_{n}n(n-1)t^{n-2} + (R - 2a)\sum_{n=1}^{\infty} a_{n}nt^{n-1} + \frac{1}{C}\sum_{n=0}^{\infty} a_{n}t^{n} = 0$$
(13)

Setting n-2=m in the first summation and n-1=m in the second summation yield to

$$\sum_{m=0}^{\infty} L_0 a_{m+2} (m+2)(m-1)t^m + (R-2a)a_{m+1} (m+1)t^m + \frac{1}{C}a_m t^m - a_{m=1}^{\infty} a_{m+1} m(m+1)t^m = 0$$
(14)

This gets to

$$2a_{2}L_{0} + (R - 2a)a_{1} + \frac{1}{C}a_{0} = 0$$
 (15)

Satisfying the boundary conditions requires that

$$a_0 = i(0) = I_0; a_1 = i'(0) = \frac{-RI_0}{L_0}$$
 (16)

Using  $a_0$  and  $a_1$ ,  $a_2$  can be obtained as

$$a_{2} = \frac{I_{0}}{L_{0}} \left(\frac{-1}{2C} + \frac{(R-2a)R}{2L_{0}}\right)$$
(17)

Using a recursive relation one gets to the final solution for the unknown coefficients as

$$a_{m+2} = -\frac{1}{L_0 C(m+2)(m+1)} a_m + \frac{am - (R-2a)}{L_0 (m+2)} a_{m+1}$$
(18)

As it is clear from 18, in the limit as  $m \rightarrow \infty$ ,  $a_{m+2}$ approaches to  $\frac{a}{L_0} a_{m+1}$ .

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So because  $\frac{a}{L_0} = \frac{1 - \frac{L_1}{L_0}}{T} >> 1$ , the coefficients becomes larger and larger without limit. To overcome this problem the definition of the coefficients in 12 must be changed as

$$i(t) = \sum_{n=0}^{\infty} (a_n T^n) (\frac{t}{T})^n$$
(19)

Choosing  $\frac{t}{T} = \tau$  and  $a_n T^n = b_n$  one gets to

$$i(\tau) = \sum_{n=0}^{\infty} b_n \tau^n$$
(20)

So

$$\frac{\mathrm{di}}{\mathrm{dt}} = \frac{\mathrm{di}}{\mathrm{d\tau}} \frac{\mathrm{d\tau}}{\mathrm{dt}} = \frac{1}{\mathrm{T}} \frac{\mathrm{di}}{\mathrm{d\tau}}$$
(21)

Setting 21 in 6 yields to

$$(\frac{L_0}{T} - at)\frac{d^2i}{d\tau^2} + (R - 2a)\frac{di}{d\tau} + \frac{T}{C}i = 0$$
(22)

Now the coefficients are obtained as

$$b_{m+2} = -\frac{T^2}{L_0 C(m+2)(m+1)} b_m + \frac{aTm - (R-2a)T}{L_0 (m+2)} b_{m+1}$$
(23)

As it is clear in the limit when  $m \rightarrow \infty$  one has

$$\mathbf{b}_{m+2} = \frac{\mathbf{a}T}{\mathbf{L}_0} \mathbf{b}_{m+1} = (1 - \frac{\mathbf{L}_1}{\mathbf{L}_0}) \mathbf{b}_{m+1}$$
(24)

Because  $1 - \frac{L_1}{L_0} \le 1$ ,  $b_m$  converges. Note that to obtain  $b_m$  we need  $b_0 = a_0$  and  $b_1 = a_1T$ . For  $t \ge T$  the current can be obtained solving the simple following

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differential equation

$$\frac{d^{2}i}{dt^{2}} + \frac{R}{L_{1}}\frac{di}{dt} + \frac{1}{L_{1}C}i = 0$$
(25)

$$\mathbf{i}(\mathbf{T}) = \sum_{n=0}^{\infty} \mathbf{b}_n \tag{26}$$

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$$i'(T) = \frac{T}{RC} \sum_{n=0}^{\infty} \frac{b_n}{n+1} - \frac{L_1}{R} \sum_{n=0}^{\infty} b_n$$
(27)

## **3. ELECTRICAL GAIN**

Electrical gain is the most important factor in FCG design procedure. This parameter is defined as the ratio of the electrical energy (delivered to the load)

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to the initial magnetic energy stored in the inductor. The electrical energy delivered to the load can be written as

$$W_{e} = \int_{0}^{1} R_{2} i^{2}(\tau) d\tau = R \sum_{n=0}^{\infty} \sum_{m=0}^{\infty} \frac{b_{m} b_{n}}{n+m+1}$$
(28)

So the electrical gain is obtained as

$$\frac{W_{e}}{W_{m}} = \frac{RT \sum_{n=0}^{\infty} \sum_{m=0}^{\infty} \frac{b_{m}b_{n}}{n+m+1}}{\frac{1}{2}L_{0}I_{0}^{2}}$$
(29)

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## 4. EXAMPLES AND RESULTS

Consider a circuit as shown in Figure 1. It is supposed that the initial current in the circuit is 1 Ampere. The current and capacitor voltage waveforms for different values of  $\frac{R}{a}$ ,  $L_0 = 10$ mH,  $L_1 = 0.5\mu$ H, C = 0.05nF, and  $T = 20\mu$ s are shown in Figure 3. The electrical gain ratio is shown in Figure 4 for different values of  $\frac{R}{a}$  and  $\frac{L_0}{L_1}$ .

## **4. CONCLUSIONS**

A simple one-dimensional approach is given for analysis and design of CFCG. The current gain and the electrical gain are obtained. This approach is based on the circuit principles, so it can be used for the design of CFCG up to few hundred megahertz. For higher frequency design and analysis two or three-dimensional methods must be used which is the subject of the future work of the authors. As it is clear from the figures, this device can be designed for electrical gain around 10000.

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