Journal scientific and applied research, vol. 27, 2024
International Journal

Original Contribution

ISSN 1314-6289 (Print)
ISSN 2815-4622 (Online)

ANALYSIS OF THE OUTPUT VOLTAGE SPEKTRUM OF A PARAMETRIC MICROWAVE CONVERTER

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ABSTRACT: *In this scientific paper, we have considered a method for determining the complex reflection coefficient based on spectral analysis of the output voltage of a parametric microwave converter.*

KEY WORDS: *Microwave converter, Spectral density, Harmonics, Pulse generator, Output voltage.*

1. Introduction

The modern stage of development of society is characterized by the wide use of complex radio communication systems in various areas of human activity. Radio communication systems, radar, radio navigation, radio control, space communications, television, telecommunications, etc. play a huge role in the life of modern humanity. The main technical characteristics of radio communication systems for various purposes depend significantly on the parameters of the microwave path, which includes the entire set of functional units and elements from the microwave generator to the antenna. An effective method for increasing the reliability of the microwave path, which is in harsh operating conditions, is the use of built-in control tools that allow you to evaluate the operability of individual functional units and the entire path as a whole.

2. Related work

Let us consider the case of periodic manipulation of the parameters of the microwave converter. In this case, we will limit ourselves to the case in which in each stationary state only one channel of the amplitude-phase converter (AFC) is connected to the detector converter. The number of stationary states will be taken to be four. This case corresponds, for example, to the use of a 12-pole

AFC in the circuit of a switching converter. The structural diagram of the built-in switching converter for this case is shown on Fig. 1.

The clock pulse generator produces a sequence of short pulses, which, through the control device, act on the microwave switch, which ensures the periodic alternate connection of oscillations from the AFC outputs to the power sensor.

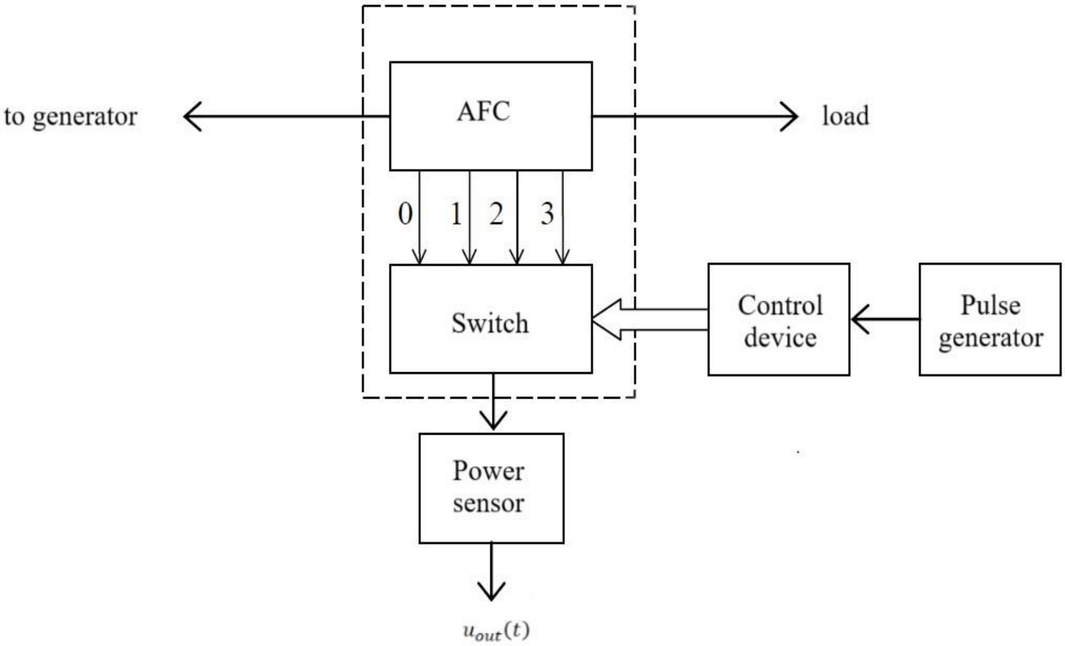

Fig. 1. Structural diagram of a microwave converter with periodic channel switching

In this case, the output voltage $u_{out}(t)$ of the switching converter has the form of a periodic sequence of pulses Fig. 2. We will designate the period of this voltage as T, and the duration of an individual pulse is equal to $t_i = T/4$. [1, 4]

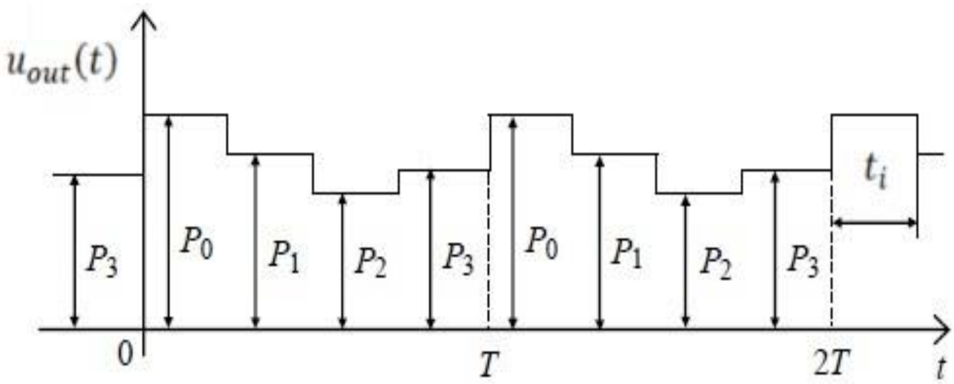

Fig. 2. Voltage at the output of a microwave converter during periodic switching

We will perform further analysis for the microwave converter model defined by the system of equations. We will additionally assume that the modul of the equivalent parameters A_i are identical: $|A_i| = |A|$. This condition corresponds to the absence of directional properties of the AFC channels and is satisfied with high accuracy of impedance sensor for the interference and polarization types at the center frequency, as well as for the most widely used circuits of twelve-pole converters. We will also assume that $q_i = q$. This requirement is not strict, since there are methods for equalizing the transmission coefficients of multi-pole devices in a wide frequency band with a high degree of accuracy. In this case, the output voltage $u_{out}(t)$ over a time interval equal to the period T is specified as a piecewise continuous function:

$$u_{out}(t) = \begin{cases} P_0 = qE_\text{г}^2 \dfrac{\left[1+|A\Gamma|^2+2|A\Gamma|\cos(\varphi+\alpha_0)\right]}{\Delta}, & \text{if } 0<t<T/4; \\ P_1 = qE_\text{г}^2 \dfrac{\left[1+|A\Gamma|^2+2|A\Gamma|\cos(\varphi+\alpha_1)\right]}{\Delta}, & \text{if } T/4<t<T/2; \\ P_2 = qE_\text{г}^2 \dfrac{\left[1+|A\Gamma|^2+2|A\Gamma|\cos(\varphi+\alpha_2)\right]}{\Delta}, & \text{if } T/4<t<3T/4; \\ P_3 = qE_\text{г}^2 \dfrac{\left[1+|A\Gamma|^2+2|A\Gamma|\cos(\varphi+\alpha_3)\right]}{\Delta}, & \text{if } 3T/4<t<T, \end{cases} \tag{1}$$

where $\alpha_i -$ are the arguments of the equivalent complex parameters A_i.

Spectral analysis of a periodic function $u_{out}(t)$ is reduced to its expansion into a Fourier series, which can be represented as [2, 3]

$$u_{out}(t)=\frac{\alpha_0}{2}+\sum_{\text{к}=1}^{\infty} U_k \cos(k\Omega t+\theta_k) \tag{2}$$

where $\frac{\alpha_0}{2} -$ constant component;
U_k, $\theta_k -$ amplitude and initial phase of the k harmonic;
$\Omega = 2\pi/T -$ angular frequency of the output voltage.

Let us first calculate the spectral density of $S(j\omega)$ fragment of a function $u_{out}(t)$ with a duration equal to the period T, which we define as the sum of the spectral densities of four pulses whose heights are equal to P_i, where $i = 0, 1, 2, 3$:

$$S(j\omega) = \sum_{i=o}^{3} S_j(j\omega) \tag{3}$$

Taking into account the expression for the spectral density of a single rectangular pulse, as well as the shift theorem, we can represent (3) in the following form

$$S(j\omega) = \frac{2}{\omega}\sin\left(\frac{\omega t_i}{2}\right)(P_0 e^{-j\frac{\omega t_i}{2}} + P_1 e^{-j\frac{\omega 3 t_i}{2}} + P_2 e^{-j\frac{\omega 5 t_i}{2}} + P_3 e^{-j\frac{\omega 7 t_i}{2}}) \quad (4)$$

Assuming in (4) $t_i = T/4$, we determine the value of the spectral density at frequencies, where $-$ is a positive integer. After a series of transformations, we obtain

$$S(jk\Omega) = \frac{T}{2\pi k}\left\{\left[(P_0 - P_1)\sin\left(\frac{\pi k}{2}\right) + (P_2 - P_3)\sin\left(\frac{3\pi k}{2}\right)\right] + j\left[(P_1 - P_2)\cos(\pi k) + (P_2 - P_3)\cos\left(\frac{3\pi k}{2}\right) + (P_3 - P_0)\right]\right\} \quad (5)$$

From (5) it follows that for frequencies corresponding to odd values *k = 1, 3, 5..., 2l +1*, where *l = 0, 1, 2...*, we can write

$$S[j(2l+1)\Omega] = \frac{T}{2\pi(2l+1)}(-1)^l[(P_0 + P_3 - P_1 - P_2) + j(P_2 + P_3 - P_1 - P_0)] \quad (6)$$

For frequencies with even values , where from (4.5) it follows that

$$S[j(2m\Omega)] = \frac{T}{4\pi m}[(P_1 + P_3 - P_0 - P_2) + j(-1)^m(P_0 + P_2 - P_1 - P_3)] \quad (7)$$

In particular, if *k = 2, 6, 10,...* (which corresponds to the values *m = 1, 3,..., 2r + 1*, where *r = 0, 1, 2,...*), then from (7) we obtain

$$S[j2(2r+1)\Omega] = \frac{T}{2\pi(2r+1)}(P_1 + P_3 - P_0 - P_2) \quad (8)$$

If *k = 4, 8, 12,...* (which corresponds to the values *m = 2, 4, 6,...*), then from (7) it follows that *S(jkΩ) = 0*. This indicates that the spectrum does not contain even harmonics with numbers multiple of four.

We will calculate the amplitudes and initial phases of the harmonics of the signal spectrum using the relationship between these parameters and the spectral density of a fragment of this signal. [2]

$$U_k = \frac{2}{T}|S(jk\Omega)|$$

(9)

$$\theta_k = arctg\frac{ImS(jk\Omega)}{ReS(jk\Omega)}$$

(10)

Substituting (6) into formulas (9) and (10) we obtain for odd harmonics of the spectrum

$$U_{2l+1} = \frac{\sqrt{2}}{\pi(2l+1)} \sqrt{(P_0 - P_2)^2 + (P_1 - P_3)^2}$$

(11)

$$\theta_{2l+1} = (-1)^l arctg\left(\frac{P_2 + P_3 - P_1 - P_0}{P_0 + P_3 - P_1 - P_2}\right)$$

(12)

Substituting (8) into formulas (9) and (10), we obtain for even harmonics of the spectrum with numbers *k = 2, 6, 10,...*

$$U_{2(2r+1)} = \frac{1}{\pi(2r+1)} |P_1 + P_3 - P_0 - P_2|$$

(13)

$$\theta_{2(2r+1)} = \begin{cases} \pi/2 & if \quad (P_1 + P_3 - P_0 - P_2) > 0 \\ -\pi/2 & if \quad (P_1 + P_3 - P_0 - P_2) < 0 \end{cases}$$

(14)

Let us determine the constant component of the output voltage spectrum using the relation given in:

$$\frac{a_0}{2} = \frac{1}{T}\int_0^T u_{out}(t)dt = \frac{1}{4}\sum_{i=0}^{3} P_i$$

(15)

Now we substitute relations (4.11) - (4.15) into formula (4.2). As a result, we arrive at the following spectral representation of the converter output voltage

$$u_{out}(t) = \frac{1}{4}\sum_{i=0}^{3} P_i + \frac{\sqrt{2}}{\pi}\sqrt{(P_0 - P_2)^2 + (P_1 - P_3)^2}\ \sum_{i=0}^{\infty} \frac{1}{2l+1} cos\left[(2l+1)\Omega t + (-1)^l\, arctg\left(\frac{P_2 + P_3 - P_1 - P_0}{P_0 + P_3 - P_1 - P_2}\right)\right] + \frac{1}{\pi}|P_1 + P_3 - P_0 - P_2| \sum_{r=0}^{\infty} \frac{1}{2r+1} cos[2(2r+1)\Omega t \pm \pi/2] \quad (16)$$

Like that, the spectrum of the output voltage of the periodic manipulation of the parameters of the microwave converter contains a constant component, all odd harmonics whose amplitudes are proportional to the value $\sqrt{(P_0 - P_2)^2 + (P_1 - P_3)^2}$, as well as even harmonics with numbers *k = 2, 6, 10,...,* whose amplitudes are proportional to the value $|P_1 + P_3 - P_0 - P_2|$.

The initial phases of the odd harmonics are determined by the output voltage readings P_j, and the initial phases of the even harmonics do not depend on these readings. Since the readings P_j are associated with both the module and the argument of the complex radio communication systems, the amplitudes and initial phases of the spectral components carry information about the measured parameters, which makes it possible to solve the measurement problem. [3, 4]

5. Conclusion

In this article, we have considered a method for determining the complex reflection coefficient based on spectral analysis of the output voltage of a parametric microwave converter. The possibility of obtaining information about the module and the argument of the reflection coefficient based on the analysis of the amplitudes and initial phases of the spectrum components is shown. Algorithms have been developed to correct multiplicative and frequency errors. The possibility of linearization of the algorithm for determining the complex reflection coefficient of the module has been proven.…

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