Developing of Homodyne Detection at Equipment Design for Experimental Investigation of Microwave Propagation

Yu. Gimpilevich, I. Shirokov

Abstract — **The homodyne detection of useful signal at equipment design, is proposed. The possibility of discrete phase change for frequency shift of test-signal is suggested. The equipment design for amplitude and phase progression is described. The results of experimental investigations are presented.**

Keywords — **homodyne detection, phase shifter, microwave propagation, amplitude and phase measurements**

I. INTRODUCTION

Coherent (and specifically, homodyne) detection has proven to be simple, highly sensitive and accurate and is operational over wide dynamic ranges. It has found wide use in the simultaneous measurement of the amplitude and phase of fields in open and closed structures, of scattered fields, of transmission and insertion parameters of devices, and of device reflection coefficients. Since homodyne detection of a modulated signal is accomplished by synchronously mixing with the unmodulated carrier, the phase information is preserved. Also, the IF frequency is zero, and the output contains only the low modulation frequencies. These low frequencies are easily filtered and measured using highly accurate, inexpensive and reliable audio-frequency components.

In previous authors' works [1], [2] for homodyne detection the case of periodic change of test-signal phase under the linear law (within the period) was considered. Analytical equations for amplitude and initial phase calculations of harmonics of combinational current of homodyne detector were thus obtained. These equations allow estimating the results of homodyne detection for variety of practically important cases. In works [3], [4] it was shown, that for obtaining of comprehensible metrological characteristics it is necessary to provide high accuracy of phase shift setting of test-signal and high linearity of dependence of this shift in time domain.

In practice the creation of controlled linear phase shifter with comprehensible characteristics represents some difficulties, especially in a band of centimeter and millimeter waves. For eliminating of specified shortcomings the transition from continuous to discrete change of test-signal phase is proposed. This statement is based on possibility of approximation of linear function by step function. Such approach allows at adjustment of the controlled phase shifter with high accuracy establishing discrete values of inserted phase shift on each step of switching. As a result it will provide high metrological characteristics of the radio engineering equipment, based on use of homodyne detection.

In the paper the brief analysis of homodyne detection at discrete phase shift is presented and on this basis the equipment for amplitude and phase progression measurements is described. The preliminary results of microwave propagation measurements fulfilled with this equipment are presented.

II. ANALYSIS OF HOMODYNE DETECTION AT DISCRETE SHIFT OF SIGNAL PHASE

Let's consider a case of periodic discrete change of test-signal phase. This case is realized by implementation in the test-signal channel of the discrete phase shifter, on the output of which the signal phase $\theta(t)$ changes discretely under the periodic law. The general case at which the number of discrete values of phase shift within period T is equal m (m — an integer), and $\theta(t)$ changes with step $\Delta\theta = 2\pi/m$ is considered. The step approximation of linear function (fig. 1) is thus reached.

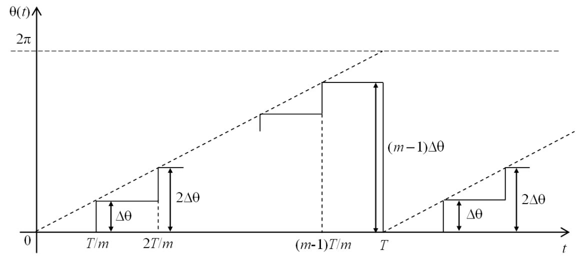

Fig.1 The law of phase change

The combinatorial current component, which flows through the non-linear element, is presented as [5]:

$$i_x(t) = \begin{cases} I_1 = k_x \cos\varphi_x & \text{if} \quad 0 < t < \dfrac{T}{m}; \\ I_2 = k_x \cos(\Delta\theta + \varphi_x) & \text{if} \quad \dfrac{T}{m} < t < \dfrac{2T}{m}; \\ I_3 = k_x \cos(2\Delta\theta + \varphi_x) & \text{if} \quad \dfrac{2T}{m} < t < \dfrac{3T}{m}; \\ \dots\dots & \\ I_m = k_x \cos\left[(m-1)\Delta\theta + \varphi_x\right] & \text{if} \; \dfrac{(m-1)T}{m} < t < T, \end{cases}$$

where $k_x = kU_xU_r$; k is the constant; U_x, φ_x are the amplitude and the phase of signal under the test; U_r is the amplitude of reference signal.

After the series of formulae transformations [5] as a result the equation for complex amplitudes of harmonics of the combinatorial current component is obtained:

$$\dot{I}_n = \begin{cases} 0 & \text{if } n \neq qm+1;\; n \neq qm-1; \\ k_x \dfrac{\sin\left(\dfrac{\pi n}{m}\right)}{\dfrac{\pi n}{m}} (\cos\varphi_x + j\sin\varphi_x) e^{-j\frac{\pi n}{m}} & \\ & \text{if } n = qm+1;\; n = qm-1. \end{cases} \quad (1)$$

From (1) it follows in a spectrum there are no all harmonics except for harmonics with numbers $n = qm \pm 1$. Using (1), let's write down expressions for amplitudes and for initial phases of spectrum components of combinatorial current:

$$I_n = \begin{cases} 0 & \text{if} \quad n \neq qm+1\,;\; n \neq qm-1\,; \\ kU_zU_r \left| \dfrac{\sin\left(\dfrac{\pi n}{m}\right)}{\dfrac{\pi n}{m}} \right| & \text{if} \quad n = qm+1\,,\; n = qm-1\,. \end{cases} \quad (2)$$

$$\psi_n = \begin{cases} \text{not defined} & \text{if } n \neq qm+1\,;\; n \neq qm-1\,; \\ \varphi_x - \dfrac{\pi n}{m} + \arg\left[\sin\left(\dfrac{\pi n}{m}\right)\right] & \text{if } n = qm+1\,,\; n = qm-1\,. \end{cases} \quad (3)$$

Let's analyze some properties of obtained spectrum. At the spectrum there is first harmonic ($q = 0$), and also harmonics with numbers $m \pm 1$ ($q = 1$), $2m \pm 1$ ($q = 2$), $3m \pm 1$ ($q = 3$) etc. Amplitudes of harmonics are directly proportional to amplitude of measuring signal under the test, and initial phases coincide to its initial phase within a constant. Amplitudes of spectrum harmonics decrease with growth of harmonic number. With increasing of discrete values number of phase shift m the frequency distance between the first harmonic and the nearest to it increases, that improves conditions for selection of the first harmonic with the help of band-pass filter. If number of discrete values of phase shift m increases beyond all bounds ($m \to \infty$) from (2) and (3) it follows in a limit in a spectrum there is only first harmonic with maximum amplitude $I_{1\max} = kU_xU_r$ and initial phase $\psi_1 = \varphi_x$, that, as is known [1], [2], corresponds to the linear law of phase shift change.

III. Example of the Spectral Analysis at Five-Step Change of Signal Phase

As an example the spectrograms of amplitudes and initial phases for case $m = 5$ are shown in fig. 2*a* and 2*b*. Spectrograms are calculated by means of formulae (2) and (3). The spectrogram of amplitudes is plotted in normalized kind.

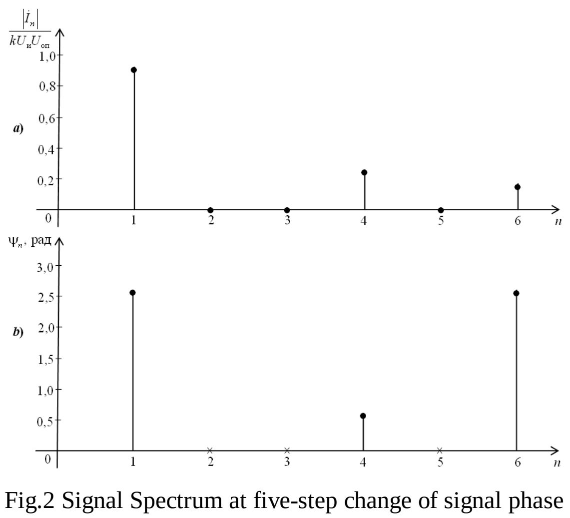

Fig.2 Signal Spectrum at five-step change of signal phase

The normalization was carried out concerning the maximum magnitude of amplitude of the first harmonic at linear change of phase shift ($I_{1\max} = kU_xU_r$). The spectrogram of initial phases is plotted at $\varphi_x = \pi$. From fig. 2 it follows at $m = 5$ in a spectrum there are harmonics with numbers 1, 4, 6, 9, 11 etc. The amplitude of the first harmonic is 0,935 from $I_{1\max}$. The frequency distance between the first and the nearest to it the fourth harmonic is 3Ω.

It is shown, that the model of homodyne detector at discrete change of test-signal phase is more general than in [1], [2]. As the special case, at limiting $m \to \infty$ it follows from this model the model with linear change of phase shift. Realization of homodyne detector with discrete change of an initial phase of test-signal provides higher metrological characteristics of radio engineering system as in this case there is a possibility of separate adjustment of inserted phase shifts by the controlled phase shifter on each step.

IV. Equipment Design for Experimental Investigations of Microwave Propagation

The investigation of microwave propagation in a turbulent atmosphere is the important scientific and technical problem. Now the theoretical basis of amplitude and phase fluctuations of electromagnetic wave in an opened links is well developed [6]. The considerable number of works is devoted also to investigations of electromagnetic wave's angles-of-arrival fluctuations [7], [8]. But the experimental researches spent now, basically did not concern the phase progression fluctuations. That is true because the method and equipment, that let us adequately carry out the measurement of phase progression fluctuations on extended links is absent. The creation of such method and measuring equipment [9, 10], based on homodyne method of signal detection, described above, allows implementing the experimental researches of amplitude and phase progression fluctuations with high metrological reliability [7].

The scheme of equipment for measurement of receiving microwave signal amplitude and phase progression is shown in fig.3. The equipment consists of two parts: main part and transponder, which are placed on opposite sites of the link under the test. One consists of microwave oscillator (MWO), mixer (MIX), low frequency selective amplifier (LAM), amplifier-limiter (LIM), amplitude detector (AD), phase detector (PD), low-frequency oscillator (LFO), VHF transmitter (TX), Y-circulators, microwave antennas, microwave amplifier (MAM), controlled phase shifter (CPS) and VHF receiver (RX).

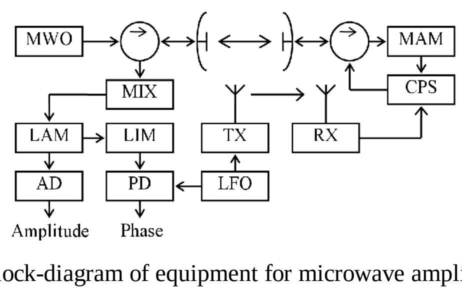

Fig.3 Block-diagram of equipment for microwave amplitude and phase progression measurements

Let's consider the equipment operation. The initial microwave oscillations are described by the following expression:

$$u_1(t) = u_0 \sin\left(\omega_0 t + \varphi_0\right),$$

where u_0 is the amplitude, ω_0 is the frequency, φ_0 is the initial phase. These oscillations are generated with microwave oscillator at first part of testing link and radiated in the direction of another part. The primary received oscillations are characterized by the generalized multiplier L, taking into account the microwave fading, the antennas gain etc and ones are characterized by the phase progression $k_0 d$ ($k_0 = 2\pi/\lambda_0$ is the microwave constant, d is the length of the link). In transponder the CPS implements the monotonous phase shift with the discrete step, described above, which leads to the frequency shift of microwave signal:

$$u_3(t) = u_0 L \sin\left[\left(\omega_0 + \Omega\right)t + \varphi_0 + k_0 d + \varphi_{LF}\right],$$

where φ_{LF} is the initial phase of the low frequency control signal. The frequency-phase transformed microwave oscillations are radiated back in the direction of the first part of the link under the test. The secondary received oscillations characterized by the additional fading and additional phase progression $k_0^{/} = 2\pi/\lambda_0^{/}$ taking into account the frequency shift of microwave signal. The equality $k_0 \approx k_0^{/}$ can be assumed. This secondary received microwave signal is mixed with the origin microwave signal; AMPL selects and amplifies low frequency difference of these microwave signals. This low frequency signal is described by the following expression:

$$u_5(t) = u_0 L^2 \sin\left(\Omega t_0 + 2k_0 d + \varphi_{LF}\right). \qquad (4)$$

From (4) it is shown that the frequency ω_0 and the initial phase φ_0 of origin microwave signal are absent, the factor L^2 defines the microwave channel fading, the factor $2k_0 d$ defines the microwave phase progression. The amplitude and phase detectors discriminates these factors. Generally these values are variable ones in time domain and ones depend on changing of propagation condition.

So, presented homodyne method of signal detection, based on discrete changing of test-signal phase, lets measuring the fluctuations of received microwave signal amplitude and phase progression on the line-of-sight link.

V. Experimental Investigations

In September-October, 2009 on the basis of proof ground of Sevastopol National Technical University the experimental researches of fluctuations of amplitude and of phase progression of microwave signal have been carried out at microwave propagation on line-of-site link [11]. The measurements were carried out with the help of described above equipment. The link length was 150 m. The microwave signal frequency was 9.4 GHz. The microwave oscillator output power was 15 dBm. The main block microwave antenna gain was 23 dB, the transponder microwave horn antenna gain was 15 dB. The transponder microwave amplifier gain was 20 dB.

The results of ten-days measurements are shown in fig. 4. The measurements were started on September 26. The *X* axis represents the time in hh:mm:ss. In plot (a) the microwave phase progression in degrees is shown. In plot (b) the receiving microwave signal amplitude in relative units is shown. In plot (c) the atmospheric pressure in kPa is shown. In plot (d) the wind speed in m/s is shown. In plot (e) the air moisture in percents is shown. In plot (f) the air temperature in °C is shown.

Obviously the phase progression of microwave propagation is in some dependence of atmospheric pressure and air moisture. In turn the last value is in dependence of air temperature. The presence of wind doesn't change the average value of microwave phase and amplitude, but one changes the level of fluctuations. The amplitude and phase fluctuations of microwave propagation are smooth at night time and rough at day time. As we can see at relatively unsteady weather conditions the round clock microwave propagation phase fluctuations reaches 130 degrees (260 degrees for two way propagation). The amplitude fluctuations of microwave signal reaches 5.1 dB (taking into account the quadratic dependence of L^2) at the same conditions. We can see some regularity in phase progression of microwave. The phase progression was increased at day time and one was decreased at night time. But we observed irregularity at September 30. The phase progression for this day time interval was decreased instead increasing. The air moisture and air temperature were not changed sufficiently during this time, but atmospheric pressure had certain minimum.

VI. Conclusion

The advantages of homodyne detection with the discrete law of test-signal phase change were shown. Such approach lets implementing of measuring equipment with excellent metrological features, which is assigned for investigations of amplitude and phase progression at microwave propagation. With the help of mentioned equipment unique data on fluctuation of phase progression of microwave in conjunction with microwave amplitude fluctuation in relation with weather conditions can be obtained. These data let building more adequate models of microwave propagation. All of that let understanding the propagation processes more exactly and investigate "thin structure" of electromagnetic field.

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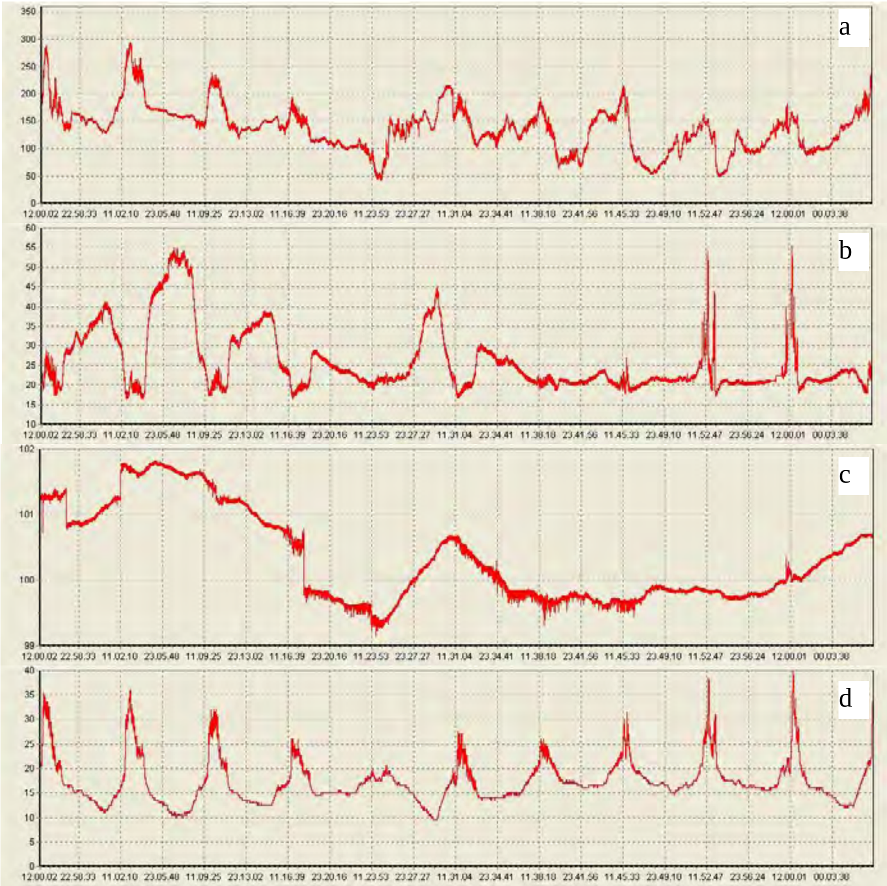

Fig.4. Ten day’s measurements of phase progression and amplitude fluctuations in relation to weather conditions