Investigation of Influence of Frequency Instability of Reference Oscillator on the Accuracy of Homodyne Measurements of Phase Progression Fluctuations on Microwave Line-of-Sight Links

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Abstract

In this paper the investigation results of the influence of frequency instability of reference oscillator on the accuracy of homodyne phase measurements are presented. The diagram of dependences the root-mean-square measurement error from the measurement line length at different frequency instability of reference oscillator is charted. The recommendations for selecting measurement line length and frequency instability of reference oscillator are given.

1. Introduction

All homodyne method measurements are based on the principle of the initial generation wave using as heterodyne signal for the same wave but passed through an investigated channel and that carry information about its parameters. One of the most important advantages of the homodyne method measurements parameters of channels, circuits, signals and materials is independence of measurements results from the initial phase of a probing signal source [1]. As a matter of fact that feature is carried out in accuracy only for stationary case when the initial phase of a probing signal is rigorously constant.

These investigations where carried out within the bounds of work of developing homodyne measurer design of amplitude and phase progression fluctuations through atmospheric channel [1, 2].

In practice the initial phase of wave that generating by any oscillator is random process because of random factors has an influence on it. For these factors can be concerned thermal and shot noises, supply voltage instability, aging, radiation influence on parameter of electronic circuit components and others. As reference oscillators were chosen temperature-stabilized quartz oscillators with relative instability of frequency equal to 10^{-7}.

It is obvious that the low-frequency fluctuation components of the oscillator's initial phase practically will not tell on the homodyne conversion results. However the high-frequency components of fluctuation spectrum can exert significant influence and distort the measurement results. As a result of this it is necessary to carry out estimation of the phase fluctuations influence on the homodyne frequency conversion results.

The main goal of this work is evaluate limiting range for those homodyne measurements of phase progression fluctuations on microwave line-of-sight links can be carried out and to present requirement for the reference microwave oscillator stability.

2. Main Part

Let's consider briefly the device and working principle of the homodyne radio metering by the example of block diagram of the device that realize the homodyne method measurements of amplitude-phase property the communications channel. The same way any other investigated matter can be used as the channel. The block diagram of the device is presented on figure 1.

On figure 1 next marks are used: CPS — controlled phase switcher; AL — amplitude limiter; AD — amplitude detector; PD — phase detector; Tx — transmitter; Rx — receiver.

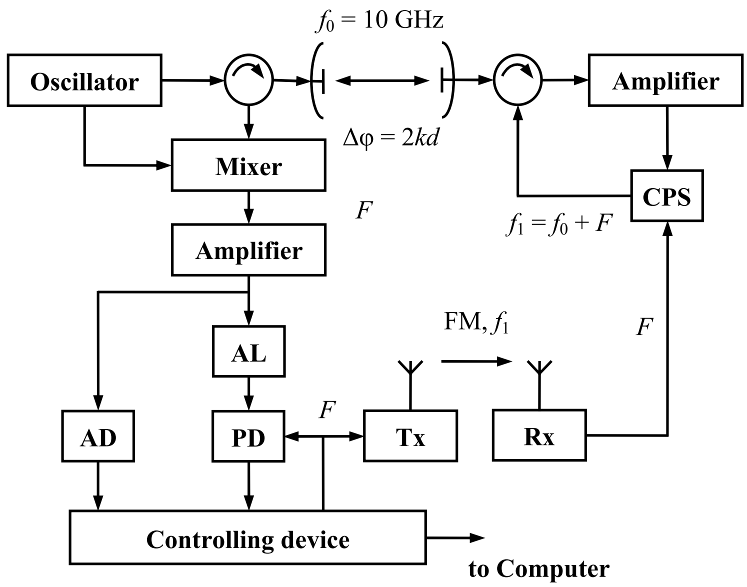

Figure 1 — The block diagram of the device the homodyne method measurements of amplitude-phase property the communications channel

The probing signal that generated by reference oscillator is a harmonic one with wave length 3 cm.

Taking into account the presents of interfering factors the reference signal voltage that come from oscillator to the homodyne converter first input can be written in the form of random narrow-band signal [2]

$$u_{\mathrm{ref}}(t)=U_{\mathrm{ref}}(t)\cos\left[\psi_{\mathrm{ref}}(t)\right]=U_{\mathrm{ref}}\left(t\right)\cos\left[\omega_0 t+\theta_0+\xi(t)\right], \tag{1}$$

where $\psi_{\mathrm{ref}}(t)$ — total phase of reference signal; ω_0 — probing signal frequency; $U_{\mathrm{ref}}(t)$ — amplitude is random function of time t ; θ_0 — initial phase of reference signal; $\xi(t)$ — increment of reference signal initial phase that is random function of time t .

Since the wave amplitude can be efficiently limited then later on we will think that amplitude multiplier is constant $U_{\mathrm{ref}}(t)=U_{\mathrm{ref}}=const$, at that equation (1) assumes the next view

$$u_{\mathrm{ref}}(t)=U_{\mathrm{ref}}\cos\left[\psi_{\mathrm{ref}}(t)\right]=U_{\mathrm{ref}}\cos\left[\omega_0 t+\theta_0+\xi(t)\right]. \tag{2}$$

Let's consider the function $\xi(t)$ that presents fluctuating slowly-variable (as compared with the probing signal oscillations) process. In a classic homodyne scheme the measuring signal, which arrives at the second input of the frequency converter, can be written as [2]

$$u_{\mathrm{m}}(t)=U_{\mathrm{m}}\cos\left[\psi_{\mathrm{m}}(t)\right]=U_{\mathrm{m}}\cos\left[(\omega_0+\Omega_1)t+\theta_0+\varphi_{\mathrm{m}}+\xi(t-\Delta t)\right], \tag{3}$$

where $\psi_{\mathrm{m}}(t)$ — total phase of measuring signal; U_{m} — measuring signal amplitude; Ω_1 — frequency shift, which insert by the controlled phase switcher; φ_{m} — initial phase of measuring signal; $\xi(t-\Delta t)$ — initial phase increment of measuring signal, that presents the same random function of time t , as in equation (2), but lagging relative to one; Δt — latency time of measuring signal relative to reference one.

The latency time of measuring signal relative to reference one for concerned case define by the next equation

$$\Delta t = 2L/c\,, \tag{4}$$

where L — line length; $c = 3\times10^8$ m/s — electromagnetic constant.

Taking into account equation (2) and (3) difference component of current that flow through the nonlinear element of homodyne frequency converter [2] take by the next way

$$i_{\text{dif}}(t) = kU_{\text{ref}}U_{\text{m}}\cos\left[\Omega_1 t + \varphi_{\text{m}} + \xi(t-\Delta t) - \xi(t)\right]. \tag{5}$$

Let's present the equation (5) in the next form

$$i_{\text{dif}}(t) = kU_{\text{ref}}U_{\text{m}}\cos\left[\Omega_1 t + \varphi_{\text{m}} + \Delta\varphi(t,\, \Delta t)\right], \tag{6}$$

where k — proportionality coefficient; $\Delta\varphi(t,\, \Delta t)$ — fluctuating phase progressions at the latency time Δt.

For the numerical analysis of the reference oscillator frequency instability influence to precision of phase measurements the model of measuring system was carried out in the software package MathLab. In this model the law of reference oscillator frequency variation was taken as normal one. The sampling time of random variable was taken equal to a transient-process time in the reference microwave oscillator. The value of root-mean-square frequency error was calculated by the next ratio:

$$3\sigma_\omega = \omega_0 N\,, \tag{7}$$

where N — relative instability of reference oscillator frequency.

The response time τ of the booster oscillating system can be expressed the next way

$$\tau = 2Q/\omega_0\,, \tag{8}$$

where Q — Q factor of the booster oscillatory system.

The numerical simulations results of root-mean-square error of the phase progression fluctuation that are expressed in degrees are shown on figure 2. On this figure the graph of dependence $\sigma_{\Delta\varphi}(L)$ at different relative instability N of reference oscillator frequency are presented. The value L was varied within 0 to 10 km.

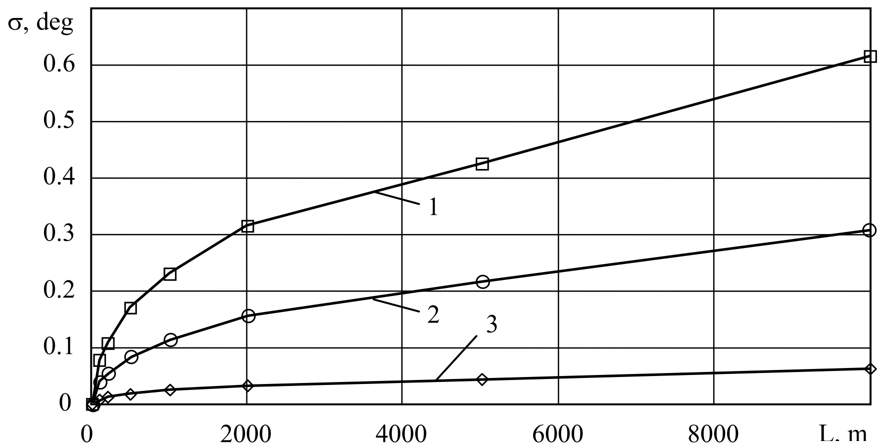

Figure 2 — The dependence of root-mean-square error of the phase progression fluctuation from the line length
1 — at $N = 10^{-6}$; 2 — at $N = 5\cdot10^{-7}$; 3 — at $N = 10^{-7}$

As follows from diagrams the error of the phase progression determination by homodyne method is increased at the line length growing and frequency relative instability increasing. At the line length $L = 1$ km [3] root-mean-square error of the phase progression of differential current component of homodyne frequency converter is: at $N = 10^{-6}$ — 0.23; at $N = 5 \cdot 10^{-7}$ — 0.11; at $N = 10^{-7}$ — 0.023 (degrees).

It should be noted that for our case the following condition is carried out

$$\frac{\Delta t}{\tau} = \frac{2\pi f_0 L}{cQ} >> 1 . \tag{9}$$

Even at the line length $L = 1$ km and Q factor equal to 200 this ratio comes to value equal 10^3. Therefore for carrying out this measurements it is necessary to provide additional action by frequency stabilization of the reference oscillator.

3. Conclusion

From the realized analyses next summaries can be made:

From figure 2 follows that value of root-mean-square error of the phase progression fluctuation is nonlinear depended from the time space Δt and at increasing this spacing it is infinitely increased. Thereof ought to next summary about that the long-term phase measurements impossible by using the classical scheme of homodyne measurements because the measurements error that induced by oscillator wave phase fluctuations can have immense value.

However at phase measurements carrying out the homodyne method have very little vulnerability to the probing signal phase fluctuations as compared with a superhet diversity reception. The phase error that is sent for fluctuations of probing signal initial phase by using the homodyne method is depended only from line length and frequency instability N of reference oscillator and independent of observation time.

For the purpose of this component error decreasing it is recommended to take the line length about 1…3 km and relative frequency instability N of reference oscillator will be better than $5 \cdot 10^{-7}$. In this case the root-mean-square error that generated by the fluctuations of probing signal initial phase will be within 0.2 degrees.

4. References

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