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PHASE TRANSIENTS IN DIGITAL RADIO LOCAL OSCILLATORS

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ABSTRACT

Phase transients that occur in microwave local oscillators are discussed. The harmful effects of these transients on coherent digital transmission are evaluated, with emphasis placed on complex modulation schemes such as 64 QAM or 256 QAM. The sources of phase transients are identified, and the methods that quantify these transients are presented along with procedures that ensure phase transient free operation of local oscillators.

INTRODUCTION

Bandwidth efficient digital radio transmission demands complex modulation schemes. 64 QAM with 4.55 bits/sec/Hz bandwidth efficiency is now widely used in long haul, high capacity microwave transmission systems. More complex modulation schemes such as 256 QAM are currently at the developement stage.

As the number of states increase and more information is transmitted, it is increasingly difficult to distinguish between states in the presence of noise which corrupts the received signal. One of the sources of degradation of the received signal is the local oscillator (LO) phase noise. LO phase noise is usually specified in terms of long and short term frequency stabilities. These parameters are well known, predictable, easily specified measured and met.

There is, however, another abnormal type of LO phase instability, that being Phase Transients (PT). A PT may be defined as a temporary LO phase instability which is not tracked by the carrier recovery loop of the receiver demodulator. A PT is an unpredictable, rare, and short lived event. The causes of these events are many and varied their measurement and diagnosis is difficult. PT's may originate externally or internally to the LO. This paper discusses the sources of PT's and their detrimental effects, particularly in digital systems with data traffic. It is shown that digitized voice transmission is quite immune to rare PT's. Test methods that quantify PT's are presented along with methods of provoking them in LO's by thermal and mechanical shocks, and power supply transients.

EFFECTS OF PHASE TRANSIENTS

The effects of LO phase transients on the Bit Error Rate (BER) of a digital transmission can be evaluated by rotating the constellation of signal states as shown in Figure 1 for 64 QAM. The extend of the degradation of the BER depends on the following factors:

a) Phase Transient Amplitude and Duration
A PT will cause errors when its peak value exceeds a certain threshold $Øe$, which brings at least some of the signal states within the boundary of adjacent ones. The value of $Øe$ for several high order modulation schemes are given in Table 1.

b) Modulation Scheme
As the angular spacing between states decreases in higher modulation schemes, the error transient amplitude necessary to cause errors decreases also. In the case of M-ary PSK, the angular spacing is equal for all states, and if a PT exceeds $Øe$, all states will be in error. In QAM systems, the corner states are the most sensitive. From Table 1, it is apparent that QAM systems are less sensitive than PSK systems and that the sensitivity increases with the complexity of modulation.

c) Presence of Noise
A noisy received signal results in higher system sensitivity to PT's. Terrestrial microwave radio under no fade conditions operates virtually error free. BER's of 10^{-20} are common. Since deep fade and LO phase transients are independent events of very low probability, the case of PT's in the presence of noise may be neglected.

d) Type of Transmitted Information
In a 135 Mb/s transmission system, a PT of 100 usec duration and sufficient amplitude results in a block of 13,500 errors. This has a serious effect on data transmission. Framing bits are lost and necessary reframing causes still more errors. Digitised voice transmission is much more tolerant. The sampling interval is 125 usec and the previously mentioned PT would cause the loss of roughly one sampling interval with little effect, since there are 8000 samples in a second.
A PT of sufficient amplitude and duration may interfere with clock and carrier recovery circuits, thus disrupting the demodulation process entirely. PT's must be kept well below leves causing errors (Table 1) or better yet, the sources of PT's must be eliminated completely.

SOURCES OF PHASE TRANSIENTS

A PT is a phase tracking error $Øe(t)$ of the carrier recovery PLL most commonly caused by the step change Δf of the LO frequency. The phase error of the second order loop with an active filter is shown in Figure 2. The peak value is proportional to the frequency step and is a function of the loop parameters. Due to other considerations such as phase noise and acquisition time, the loop cannot be optimized to minimize frequency steps.

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Instead, PT control must be achieved by controlling the sources of these transients. The undesired frequency steps must be kept below the values shown in Table 2. This is a demanding requirement considering the relative frequency change. For example, it is 0.3 ppm for an 11 GHz LO in a 64 QAM system.

Frequency steps can be generated by all components or mechanical structures which effect the LO frequency and are not absolutely stable. This general statement refers to instabilities of short duration and rare occurence over long periods of time and varied environmental conditions.

The following are some of the sources of PT's within the LO:

a) mechanical contacts within the oscillator resonator;
b) contacts within the frequency tuning mechanism;
c) contacts within frequency multipliers, output isolators and amplifiers;
d) unreliable solder joints;
e) defective components.

Sources external to the LO are:

a) unstable RF load impedance (frequency pulling);
b) unstable reference crystal oscillator monitor load impedance;
c) unstable power supply voltage (frequency pushing);
d) electromagnetic interference;
e) mechanical shocks and vibrations.

Diagnosing the sources of PT's within the LO, particularly those of rare occurence, is a difficult and tedious task. By proper LO mechanical design, selection of components and processes, PT's can be eliminated.

Sources external to the LO are much easier to identify and control. The PT's that are due to these sources are more easily predictable and can be reporduced by quantifiable external excitations. In this manner, they can be controlled by eliminating or controlling the excitations and by increasing the isolation of the LO, and/or by isolating the excitations within the LO.

TESTING PROCEDURES

In order to control and suppress the generation of phase transients, adequate techniques must be established for their measurement and characterization. These techniques serve as diagnostic tools at the design stage, and as screening methods in manufacturing.

Figure 3 shows the LO PT and microphonic sensitivity test set. It captures and displays short transients. The test set is calibrated by opening the loop and measuring the beat tone peak to peak voltage which corresponds to 360° phase shift. There are several types of excitations that can be applied to cause PT's to occur so that the LO response may be measured and recorded. Some excitations, such as mechanical shocks, vibrations or DC transients, produce repeatable responses. PT's that originate within the LO are best excited by temperature changes or localized pressure. They occur randomly with varying amplitude and shapes.

Figure 4 shows a typical LO response to mechanical shock. Figure 5 shows LO response to mechanical vibration in the frequency domain. Sharp multiple resonances of the LO mechanical structures are visible. Figure 6 shows typical PT excited by temperature change caused by mechanical contact. In LO's with PLL frequency control, the testing may be simplified by monitoring the internal loop control voltage transients, providing the LO and carrier recovery loops have the same parameters. Figure 7 shows transients measured with the test set shown in Figure 3 (top trace) and using the internal PLL (lower trace). Excellent correlation is apparent. PT measurement can be simplified further by measuring the peak value of the transient. This method provides single numerical results which are ideal for comparison or go/no go testing.

The ultimate LO testing procedure is a system performance test. A system showing such a test set is shown in Figure 8. Sixteen LO's may be tested at a time, with the possibility of adding more, if necessary. The LO's are placed in a chamber and they undergo multiple shock cycles ranging in temperature from -20° to +65° Celcius.

Actual transmitted information is being monitored, along with other data, such as frequency, power, PLL stress voltage and temperature. If a PT occurs that causes framing information to be lost, a frame loss is declared by the radio receive signal processing equipment. The information is collected by the test computer and the LO is declared to have failed the test.

In this manner, it can be assured that units that pass the test will perform perfectly in service with no unwanted phase transients.

CONCLUSIONS

Control of transient phase instabilities in digital radio LO's was discussed. Data transmission is very sensitive to these instabilities. They must be primarily prevented rather than accurately monitored, measured and assessed. Sources and the mechanisms responsible for phase transient generation must be known in order to eliminate them. For this purpose, LO's are tested under stressed conditions. Test methods and some results were presented.

REFERENCES

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(3) W.P. ROBINS PHASE NOISE IN SIGNAL SOURCES. LONDON UK PETER PEREGRINS LTD. 1982.

M	16	64	256	1024
Øe (PSK) Deg	11.25	2.81	0.70	.18
Øe (QAM) Deg	16.87	7.69	3.70	1.82

$$\emptyset e\ (PSK) = \frac{360^{\circ}}{2M}$$

$$\emptyset e\ (QAM) = 45 - \sin^{-1} \frac{\sqrt{M}-2}{\sqrt{2}\,(\sqrt{M}-1)}$$

Table 1. Phase Transient Peak Value Øe Necessary to Cause Errors

M	16	64	256	1024
Δf (PSK) KHz	5.3	1.3	.330	.085
Δf (QAM) KHz	7.9	3.6	1.74	.858

$$\Delta f = \frac{\phi e \; fn}{0.37} \qquad fn = 10\text{KHz} \qquad \zeta = 1.0$$

Table 2. Step Frequency Necessary to Cause Errors (KHz)

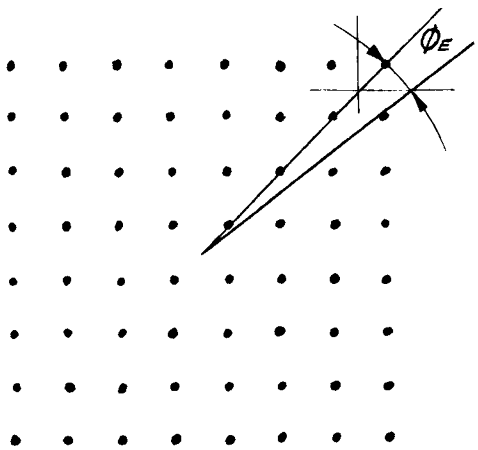

Figure 1 64 QAM constellation of signal states with carrier recovery PLL phase Error Øe causing erroneous reception of the most sensitive corner states.

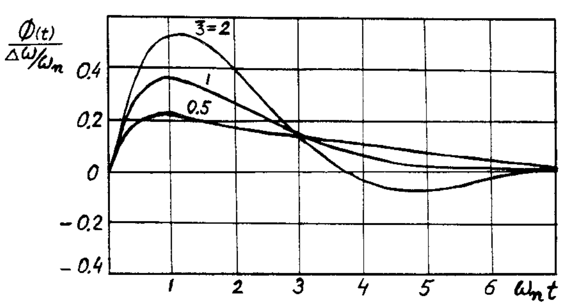

Figure 2 Transient phase error Øe (t) due to step frequency W forsecond order PLL with active filter.

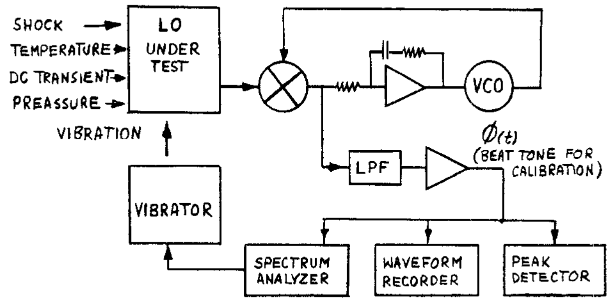

Figure 3 LO Phase transients and microphonic sensitivity test set

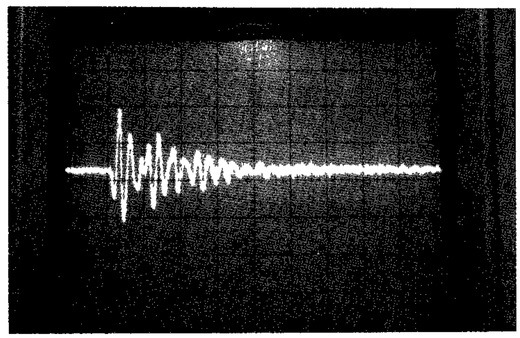

Figure 4 LO Phase transient response to mechanical shock.
72°/DIV, 200 Sec/Div

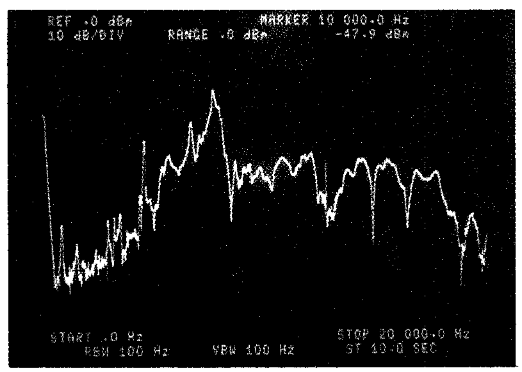

Figure 5 LO Microphonic sensitivity at 8 KHz the peak phase is 10°.

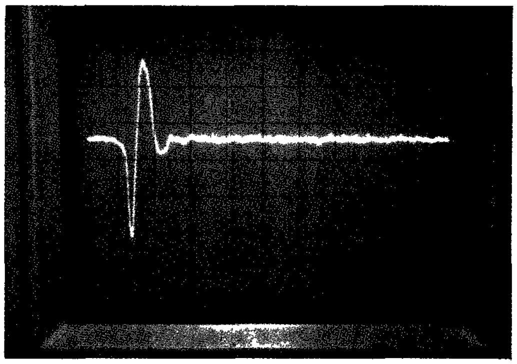

Figure 6 LO Phase transients excited by temperature change and caused by mechanical contact 36°/Div, 100 usec/Div

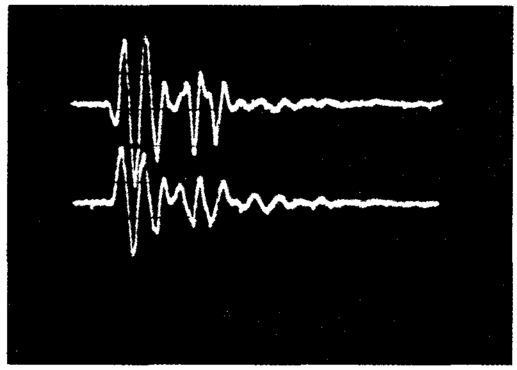

Figure 7 LO Phase transient measured with test set of Fig. 3 (top trace) and using the internal LO PLL (lower trace).

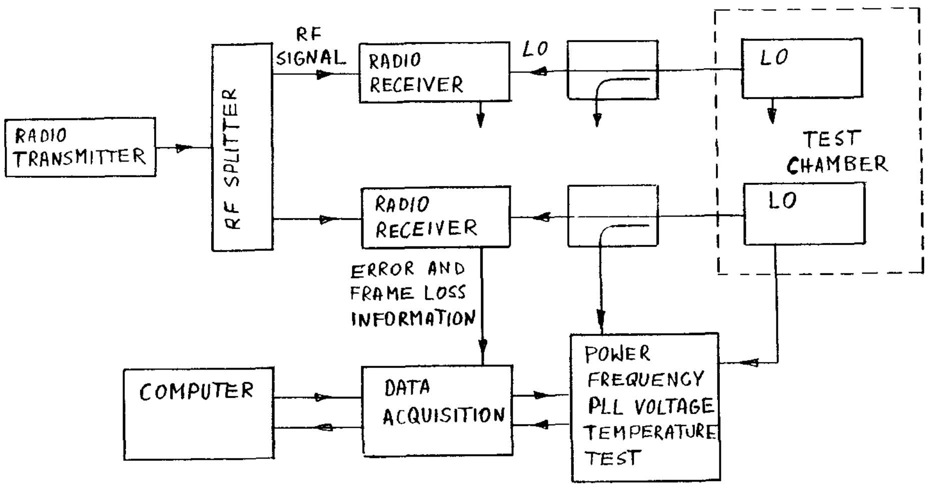

Figure 8 Environmental test set to verify system performance of LO's under thermal stress.