APPLICATION OF PHASE LOCKED MODULATORS AND PROCESSORS

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Recently much has been said about the advantages phase locking techniques offer the CATV operator. This paper is intended to further acquaint the reader with the phaselock technique, so he can better utilize the available phase locked equipment.

Phaselock is not new to the electronics industry. The first practical applications were coherent detectors in homodyne radio receivers built in the 1930's. However, the circuit complexity of a phase locked loop is so great that until recently the technique was restricted to a few specialized applications. Now, thanks to progress in components and circuit techniques, phaselock is becoming economical for a wide range of applications.

CATV application of phaselock includes precision demodulation, minimizing the subjective effects of strong local TV signals, and various phase locked headend schemes. This paper is concerned with only one of these applications of phaselock: minimizing the subjective effects of a strong local signal leaking into a subscriber's television set. This leakage problem has required the cable system to distribute strong signals on channels which are not locally used for TV broadcast. This off-channel conversion for cable distribution eliminates the leakage problem at the expense of available cable channels. New FCC rules and increasing program availability to cable systems have created pressure to use these fallow channels for some type of locally originated program. If the cable channel carrier is not exactly at the frequency of the interfering carrier, a co-channel beat will be seen on the subscriber's set.

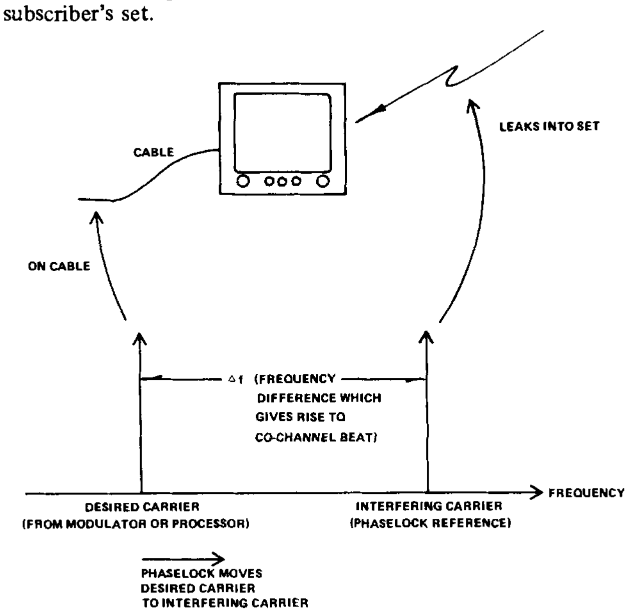

FIGURE 1. INTERFERENCE SITUATION

Figure 1 illustrates the situation where two video carriers close together in frequency are present simultaneously. The signal on the left is the desired carrier, perhaps carrying a weatherscan picture. To the right is an interfering carrier which has leaked into the subscriber's TV set. When the two signals are detected, their frequency difference will create a component Δf in the video. This shows up as black and white co-channel lines in the picture. The severity of the co-channel beat is dependent upon the relative levels of the two signals, and upon their frequency separation, Δf. Phaselock can be used here to force the desired carrier to the frequency of the interfering carrier, reducing Δf to zero and eliminating the co-channel beat.

How do we accomplish this? Figure 2 is a simplified block diagram of a phase locked modulator. A sample of the interfering signal is picked off the air and applied to a fairly narrow bandpass filter. This filter removes all energy except the picture carrier and some of the luminance sidebands. The remaining signal is the reference, which is applied to a phase detector. The output of a voltage controlled oscillator is also applied to the phase detector. The output of the phase detector is a d.c. potential proportional to the cosine (in this case) of the phase difference between the reference signal and the voltage controlled oscillator (VCO) output. This phase error is applied to a loop amplifier (normally configured as an integrator for low frequencies), whose output is the VCO control voltage. Since the amplifier has very high gain at low frequencies, it will act on the VCO in whatever manner is necessary to reduce the phase error to nearly zero. Thus, the VCO output is required to maintain a strict phase relationship to the reference signal, and hence must operate at the same frequency. The VCO output is then applied to the modulator, and the remaining modulator operation is identical to that of a non phaselocked unit. In the case of Scientific-Atlanta's Model 6300 PL Modulator, the modulation is performed at the 45.75 MHz intermediate frequency, which is then upconverted to the desired channel. A common local oscillator is used for up conversion and for down conversion of the reference. This assures phase coherency. For stability the VCO used is a voltage controlled crystal oscillator (VCXO).

Use of the reference signal directly instead of locking another oscillator to its frequency is not practical. This is because a bandpass filter cannot be realized that will adequately strip all modulation sidebands off the reference, maintaining this characteristic over all combinations of reference drift, time, and temperature. In this respect, the phase locked loop operates as a tracking filter, since its output is at the frequency of the input, and all sidebands can be suppressed to an arbitrary degree. Even so, the output can track the input carrier over a greater range than the effective filter bandwidth.

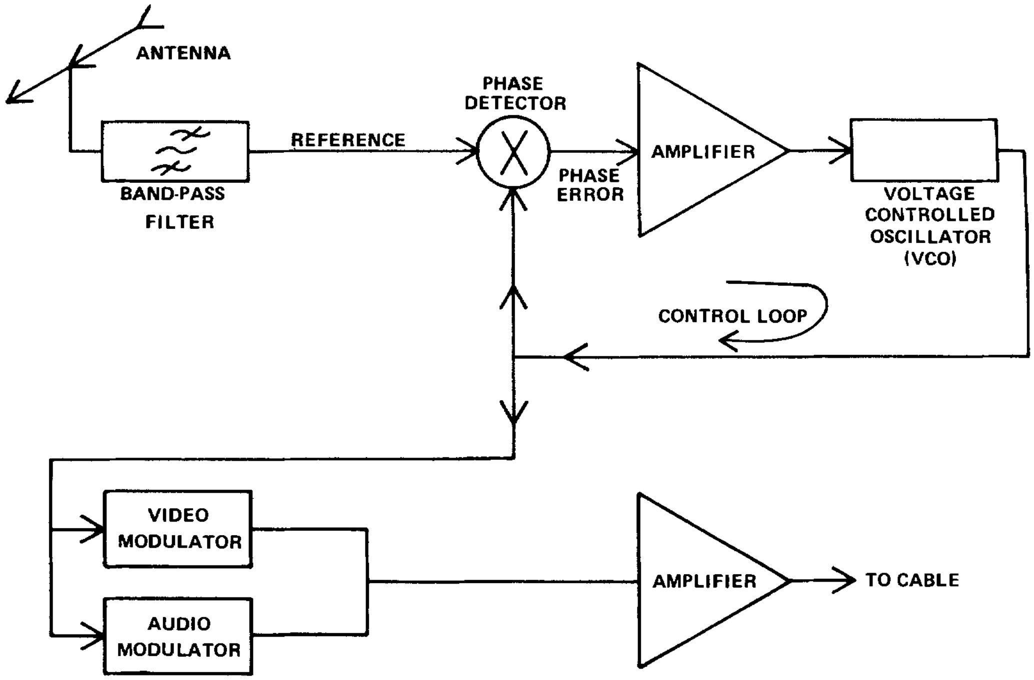

FIGURE 2. SIMPLIFIED BLOCK DIAGRAM, PHASE LOCKED MODULATOR

Before a phase locked situation can exist, the VCXO must be made to run at the same frequency as the reference. Figure 3 defines some terms that are appropriate to the acquisition of phase lock. This figure is a spectrogram centered on the free running frequency of the VCXO; as this frequency changes, it will appear to stay fixed, but other features of the spectrogram will move. The free running frequency is the frequency at which the VCXO would run if no control voltage is applied from the loop amplifier. When power is first applied, or when the reference carrier first becomes available, the loop must somehow move the VCXO frequency to the reference frequency before phase lock can be achieved. Also shown in Figure 3 is the frequency of the reference, which might appear anywhere in the spectrogram.

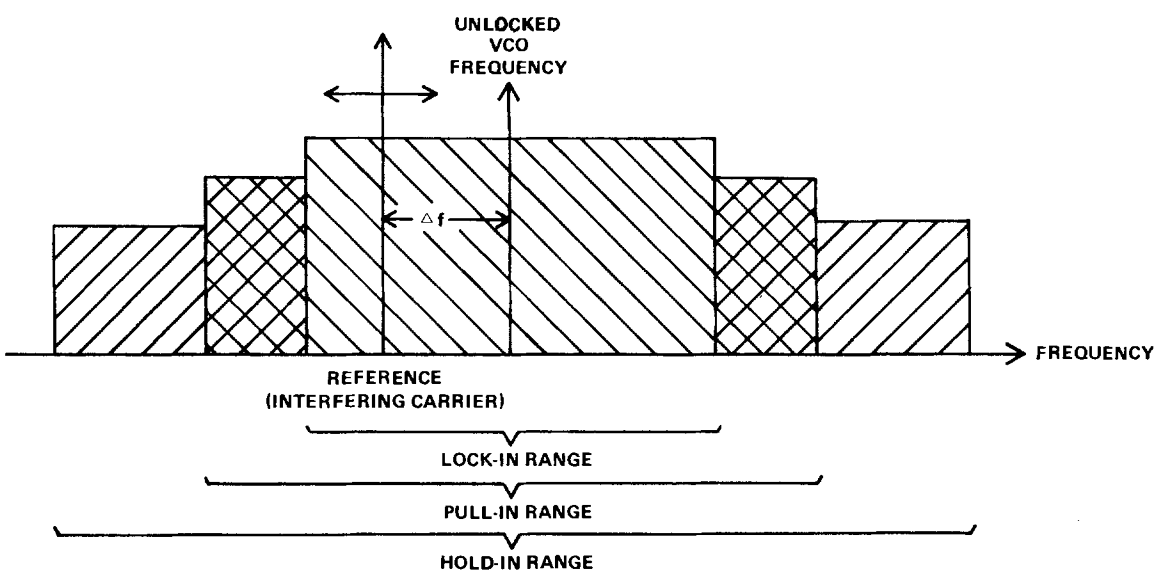

FIGURE 3. DEFINITION OF TERMS

The detailed process of bringing the VCXO into lock is quite complex and beyond the scope of this paper. However, a brief discussion of the process involved is in order. The difference between the reference and free running VCXO frequencies is defined as Δf. If the frequency difference is sufficiently small, the control loop is able to rapidly bring the VCXO into lock. The range over which this can be accomplished is called the lock-in range. For all practical purposes, the lock-in range is roughly equal to the loop bandwidth, which should be small in order to improve rejection of the reference sidebands. If the initial frequency difference is within the lock-in range, the loop will rapidly acquire. If the initial frequency difference is out of the lock-in range but within the pull-in range, the loop can theoretically lock if given enough time. However, in this range practical considerations of amplifier offset and noise are such that lock generally cannot be achieved without additional circuitry. Outside of the pull-in range, lock cannot even theoretically be achieved without additional acquisition circuitry. However, once lock is achieved, the loop is able to hold lock over a much wider range, known as the hold-in range. This is the frequency difference over which, after lock is achieved, Δf may drift and still permit the loop to remain locked. For the most useful type loop, the hold-in range is not a function of loop dynamics, but rather is a function of saturation levels of loop amplifiers or other components in the loop. Within certain practical bounds, the hold-in range may be made arbitrarily large.

Proper acquisition circuitry may be used to aid the loop in locking up at any frequency in the hold-in range. An adequate acquisition (and hold-in) range is one which permits acquisition under the worst possible initial frequency error, Δf, due to all causes. This acquisition must be without operator intervention. In order to determine the required acquisition range, we will develop a worst case error budget, taking into account all known sources of frequency error. Table 1 lists the major contributors to the error budget. The first source of error is the 1 kHz frequency tolerance imposed upon the broadcast station. Although not a frequency error, we will add in the 10 kHz broadcast carrier offset. If the acquisition range is insufficient to handle the carrier offset, then the offset must be specified when ordering the phase lock equipment or when transferring it to a different location. To the above tolerances must be added the drift of the VCXO, which might reach 5 kHz at the higher channels. This may be drift reduced to 0.2 kHz with a highly stable VCXO enclosed entirely in an oven. However, an oven is undesirable because the higher temperature will accelerate component failure, and will also increase power consumption. In addition, an oven stabilized oscillator must be allowed to warm up after turn-on or a power failure.

Another error which must be taken into account to insure that the operator does not have to "treak" the phase lock after installation, is the initial frequency setting of the VCXO. A reasonable allowance for this is 0.5 kHz.

1. BROADCAST CARRIER TOLERANCE	1 kHz
2. BROADCAST CARRIER OFFSET	10
3. VCXO DRIFT (Ch. 13, non oven controlled)	5
4. VCXO INITIAL SETTING	.5
5. CRYSTAL AGING	?
6. COMPONENT AGING	?
7. VARIATION WITH POWER SUPPLY	?
ERROR BUDGET	16.5 kHz

(For heterodyne processors, add down-conversion error)

TABLE 1. ERROR BUDGET FOR DETERMINATION OF REQUIRED ACQUISITION RANGE

So far the error budget is ±16.5 kHz and there are still several other sources of error to consider. These errors are more difficult to quantitize. They include crystal aging, frequency fluctuation with power variations, etc. In the case of a phase locked heterodyne processor, we must also add the tolerances pertaining to the station whose signal we are processing. A safe acquisition range to consider is plus or minus 25 kHz. This allows for known sources of error, plus some margin for the undefined errors.

Implicit in the discussion of safe acquisition range has been the requirement that the loop must also exhibit an adequate hold-in range. Considerations with respect to adequate hold-in range include the use of servo compensation that develops a very high gain at low frequencies, so that a significant phase error does not develop at the phase detector output. Also, the VCO must be capable of being controlled over an adequate range. For good stability, the VCO should be crystal controlled, but special design techniques are required to pull a VCXO over the frequency range required.

Several types of acquisition circuitry have been developed over the years. Probably the most common technique in communications applications is use of a triangular ramp which drives the VCO back and forth over the entire hold-in range, searching for a signal to lock to. When the VCO is driven to within lock-in range, the loop locks and the ramp is disabled. The technique works, but is relatively slow, because acquisition dynamics limit the maximum search rate. Also, if significant sidebands exist within the search range, the loop may attempt to lock to them rather than to the carrier.

Recently several types of digital phase detectors have become popular for frequency synthesis work. The most elegant is a sequential circuit, available in I.C. form, that matches the negative-going transitions of the two waveforms. This detector has the property that if one input is higher in frequency than the other, the phase detector output is maximum in the direction that drives the VCXO into lock. Thus, if this detector is used, acquisition circuitry is unnecessary. For noise free applications such as frequency synthesis, this detector is often an excellent choice. However, it tends to be overly sensitive to noise or modulation sidebands, because of its characteristic of responding only to a waveform transition. In addition, its maximum operating frequency is only about 10 MHz, so it is not useful for our present application. Another acquisition scheme involves use of a frequency discriminator, which must be accurately zero'd with the VCXO free running frequency.

Scientific-Atlanta has used an acquisition technique in our 6300 PL phase locked modulator and 6150 PL processor which to our knowledge is unique. Before the loop pulls into lock, a beat note exists at the phase detector output. The characteristics of the beat note are analyzed to determine the direction in which the VCXO must be driven in order to acquire lock. This technique permits lock to be achieved in a few milliseconds, with an initial frequency difference of fifty kilohertz. Circuit logic makes the technique insensitive to false lock on the reference sidebands as long as their amplitude is less than that of the carrier.

The visual effect of non phaselock is primarily the familiar co-channel beats, the subjective effect being dependent upon the frequency difference. When the two signals are phaselocked, a ghost of the interfering signal will still be seen on the screen. No satisfactory method exists for eliminating this ghost except to eliminate the signal leakage. However, several things may be done in order to minimize the subjective effect of the ghosting. The subjective effect depends upon the relative magnitude of the interference, upon picture content, upon the relative phase of the two carriers, and upon the relative frame rates of the two pictures.

Some reduction of the effect of ghosting may be obtained, in the case of display of text only, by utilizing white lettering on a black background. This is possible because black will then occupy the larger area, and a ghost is less noticeable with black picture content than with white. Black level is less affected by the ghost because of its higher carrier amplitude. Also a subjective effect is apparently at work here.

Phase angle between the two carriers is important because the effects of modulation of the interfering carrier on the overall instantaneous carrier amplitude may be shown to be dependent upon the manner in which the two carriers add vectorially. Unfortunately, this characteristic cannot be put to use in minimizing interference, because the relative phase of the two carriers at the home receiver cannot be maintained over time.

The relative frame rates of the two pictures is important because sync information is transmitted at a blacker-than-black level, and if the ghost sync bars are moving through the desired picture, a more distracting situation is seen than would be seen if the sync bars were stationary. For this reason, the operator should be careful to operate at the same frame rate as that of the interfering signal, if maximum picture quality is to be maintained. This should not be a problem if both the desired cable picture and the interfering picture are synchronized to broadcast quality color sync generators: the frequency stability demanded ensures that the two frame rates will be so nearly identical that the sync bar will move slowly if at all. Such may not be the case if the local origination picture is in black and white. This is because a 60 Hz field rate is traditionally used for black and white, while the field rate for color transmission is slightly retarded. This can give rise to sync bars moving rapidly in the picture. This problem may be eliminated if the local origination signal is genlocked to the interfering picture. This normally required, in addition to a camera, a sync generator capable of being genlocked to external video. To provide this video source for genlocking purposes, Scientific-Atlanta has provided a utility demodulator on its phaselocked modulator. This demodulated video output is available on the rear panel of the modulator.

Phaselock techniques have several applications in CATV systems, but phaselock should not be looked upon as a "cure for what ails you." Intelligently applied, it can be useful in several applications, including elimination of co-channel beats. As with any other tool, it must be reasonably well understood before it can be used to good advantage. For this reason, the CATV engineer considering phaselock should be sure he understands the advantages and limitations of phaselock, in order to maximize his return on investment and avoid unnecessary disappointment.

Bibliography

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