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A NEW PHASE COHERENT PARAMETRIC MIXER FOR PCM-PSK COMMUNICATIONS

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Abstract

A new phase coherent parametric mixer pumped by quadruple frequency of input signal is developed with the objects of obtaining a carrier recovery circuit for synchronous detection and a new phase regenerator with excellent characteristics, especially for high-speed four-phase communications.

Introduction

Recently, the phase-shift-keying (PSK) modulation system has attracted special interest in the microwave communication field with special emphasis on satellite and millimeter-wave communications. In PCM-PSK communication which uses multi-phase modulation, for example, four-phase to increase transmission capacity, one of the important and difficult problems is to demodulate the received signal synchronously in the receiver or regenerative repeater, because no carrier components exist in the randomly modulated PCM-PSK signal. Hitherto, in order to recover the carrier signal required for synchronous detection, the received signal has been multiplied by number of phase-modulation to be a CW signal or reversely remodulated in the receiver against transmitter by the demodulated pulses.

These methods, however, are complicated in circuit and produce longer delay time to detect the carrier signal. The longer delay time of carrier recovery circuit is a serious defect, especially for high speed PCM communications, because the locking bandwidth becomes too narrow to follow the frequency variation over a wide range of operating temperature even of highly stabilized solid-state local oscillator in microwave or millimeter-wave band.

In this paper, by using a newly developed phase coherent parametric mixer pumped by quadruple signal frequency of input or received signal, we could realize a carrier recovery circuit, thereby improving the circuit complexity and delay time and reducing power consumption. Further, this phase coherent mixer can operate as a phase regenerator since a stairs-like input-output phase relation can be obtained by adjusting circuit conditions. This stairs-like phase relation can suppress the phase variation or noise of the received signal and discriminate the state of signal phase. When the domain of the received signal phase is changed, the output phase is also changed to the corresponding step of the stairs-like phase characteristic. Therefore, this circuit can operate as a regenerator for PCM-PSK signal which operates directly in the carrier signal stage without detection or baseband regeneration, thereby obtaining circuit simplification and improving regenerator characteristics[1].

Principle of Operation

Fig.1 shows the block diagram of circuit configuration. The diode (such as Schottky barrier diode and varactor diode) is pumped by a signal which has quadruple signal frequency of that of input signal. The received input signal is applied to the diode through circulator.

Input Signal: $e_i = E_i \cos(\omega_i t + \varphi)$

Pump Signal: $e_p = E_p \cos(4\omega_i t)$.

Where ω_i is input signal angular frequency and φ is the signal phase to that of pump signal.

The diode current i_d is assumed to be given by the following series expansion of the input resultant voltage of the received signal and pump signal,

$$i_d = a_0 + a_1 e + a_2 e^2 + a_3 e^3 + \cdots = \sum_{n=0}^{\infty} a_n e^n$$

$$e = e_i + e_p$$

That is, the large-signal analysis is taken in this paper. The output current having the same angular frequency with the received signal is taken out of the diode through the circulator to the output circuit. The output current can be divided into two components: one is the received signal itself which is coming out according to the coefficients of expansion, a_1, a_3, a_5, ----, and the other component is appearing from coupling or mixing between the received signal and the pumping signal. The coupling or mixing component is first appeared from the fourth expansion term, $a_4 e^4$, as follows,

$$a_4(e_i^3 \cdot e_p) \Rightarrow a_4 E_i^3 \cdot E_p \frac{1}{8} \cos(\omega_i t - 3\varphi).$$

Further, from higher ordered terms such as 6-, 9-, 11- and 14-th, we also get the mixing terms with fundamental angular frequency ω_i. The mixing term for the sixth order is $\cos(\omega_i t + 5\varphi)$, and $\cos(\omega_i t - 7\varphi)$ for the ninth term. For simplicity, the terms more than fifth are at first neglected in the following analysis. For this case, the output signal at terminal B of Fig.1 is given by the following two terms,

$$e_o(t) = K_i \cos(\omega_i t + \varphi) + K_m \cos(\omega_i t - 3\varphi),$$

where K_i and K_m denote the amplitude for each component respectively.

By the way, through the use of $2\omega_i$-idler circuit between signal and pump circuits, we can expect the same mixing term: $\cos(\omega_i t - 3\varphi)$, from only the second nonlinear term but detailed analysis is omitted in this paper.

Phase Locking of Pump Source

When the output signal of the mixer is phase-detected with the received signal whose phase is shifted by $\pi/2$, we get the following low frequency output signal,

$$e_0(t)\cdot \sin(\omega_i t+\varphi) \Rightarrow \frac{K_m}{2} \sin(4\varphi),$$

which is directly proportional to $\sin(4\varphi)$. When the received signal is four-phase PSK signal: $\varphi = \varphi_0 + (0, \pi/2, \pi, 3\pi/2)$, the output signal of phase detector is not dependent on the phase modulation term but depends only on the phase difference φ_0 between the received signal and the pump signal. Therefore, the output signal can be applied through loop-filter and DC amplifier as a phase-control signal to the voltage-controlled-oscillator (VCO) which serves as a pump source. The loop-bandwidth of phase locked loop is designed to be fairly small ($1/10 \sim 1/100$) as compared with the PCM pulse-rate in order to get noise-free carrier. Accordingly, the phase coherent pumping is always attained, and the output signal of VCO can be used as the carrier required for synchronous detection in demodulator.

Phase Regenerator

The output signal of phase coherent parametric mixer consists of two components of φ and -3φ. The two components, when represented on vector-diagram plane, rotate mutually reversely with different speed on φ. Therefore, by adjusting the amplitude relation of the two components, the resultant vector produces non-linear input-output phase characteristic like stairs which can be utilized as a phase regenerator in regenerative repeater. Fig.2 shows the input-output phase characteristic versus φ and the corresponding amplitude characteristic only on the range of φ of $-\pi/2 < \varphi < +\pi/2$. When the ratio, K_m/K_i, is 0.4, a fairly well phase regenerative characteristic can be expected. Furthermore, by taking the mixing term, $K_{m6}\cos(\omega_i t + 5\varphi)$, resulting from the sixth ordered term into account, the phase characteristic is improved, which is shown in Fig.2 by dotted line, but the amplitude variation at the phase-jumping place becomes large. The circuit conditions of K_m/K_i and K_{m6}/K_m can be adjusted by varying the pump power, signal power and bias for a given diode.

Moreover, by connecting two coherent mixers cascade, the phase regenerative characteristic can be improved. On the other hand, the amplitude variation can be removed by using Tunnel diode with limiter action for the mixer or by a succeeded limiter.

Experimental Results

Fig.3 shows the circuit configuration, which is formed on a dielectric substrate (ε = 2.65) using strip-line circuits. The input signal frequency is 2GHz and the VCO is a 2GHz transistor oscillator of common-base type, whose output power is partly (0 dBm) shared to the output terminal for synchronous demodulator through a slitted series capacitance, and the other part is fed to a Step Recovery Diode(SRD) (HP-0251) and multiplied to 8GHz by its non-linearity. The multiplied output power of about 0 dBm is served as a pump power through strip-line BPF to the mixer. The mixer is a Schottky Barrier Diode (SBD) sandwitched by both the input circuit with short for pump frequency $4\omega_i$ and the pump circuit with short for input signal ω_i. The phase detector consists of triplate wideband hybrid and two SBD's of balanced type. The detected signal is fed back to the SRD through loop-filter and DC amplifier. The SRD serves as a variable capacitance to vary frequency of VCO as well as a multiplier for pumping source. The sensitivity of the VCO is high and 230MHz/volt, and the frequency stability is 1.5×10^{-3} over $0^\circ\sim60^\circ$C. The DC amplifier has gain of 24dB and bandwidth of $0\sim350$MHz, which is attached on the back of strip-line substrate and whose dimensions are 20mm × 20mm. The total circuits excluding signal circulator are formed on the dielectric substrate of dimensions of 100mm × 100mm as shown in Fig.4, whose thickness is 30mm.

Fig.5 shows the obtained phase and amplitude characteristics, which show an excellent coincidence with theory.

Fig.6 shows a process of phase synchronization of VCO, which was observed by phase-detecting the output signal of VCO with a gated (on-off) input signal. The photograph shows the presence of four states of phase synchronization. The lock-up time is less than 100nS.

Special Features

The total loop delay is about 7nS and the pull-in range of the phase locked loop is ±15MHz. These values are superior and sufficient for use in demodulator for 200∼400Mb/s PCM transmission in millimeter-wave band. The other merits of this phase coherent mixer are low power consumption and high reliability in circuit operation.

Power Consumption: 490mW,
VCO: 130mW, DC-Amp.: 360mW.
Number of Semiconductor Elements: 9,
Phase Regenerator: 5(Tr.1,SRD 1,SBD 3),
DC Amplifier: 4(Tr.3, Zener diode 1).

System Applications

We may expect the following system-applications of the phase coherent mixer by making good use of such features as: high-speed operation, high-reliability, low-power consumption, wide pull-in range, short lock-up time and others.

1. Regenerative Repeater in Carrier Stage,
2. Synchronous Demodulator, for;
   (i) Microwave-PCM Communication System,
   (ii) Quasi-Millimeter-wave Terrestrial System,
   (iii) Guided-Millimeter-Wave System,
   (iV) TDMA-Satellite Demodulator,
   (v) Satellite-Mounted Regenerative Repeater.

In conclusion, we have developed a new phase coherent parametric mixer, but the further improvement of the characteristics remains to be solved.

Acknowledgment

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Reference

(1)M.Hata, T.Ohta et.al.,"A New Direct Regenerative Repeater for PCM-PSK Microwave System", International Conference on Communications of IEEE, ICC-70-21.7(70-CP-297-COM), June 1970.

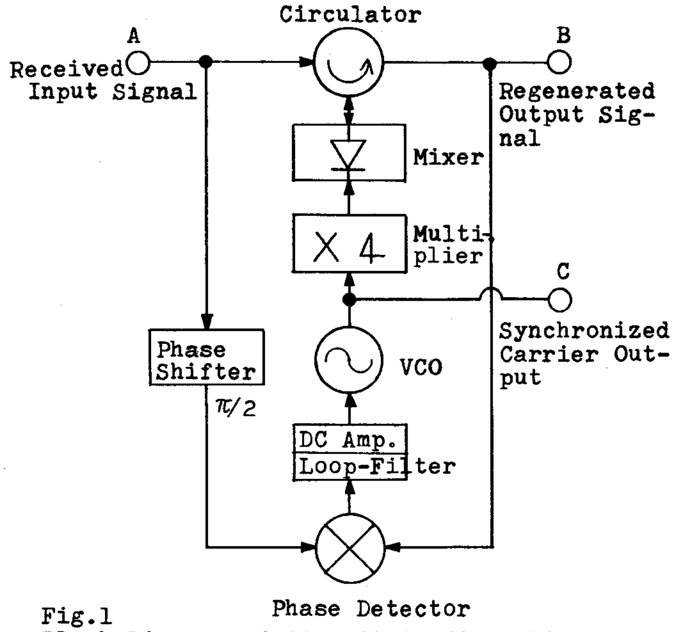

Fig.1
Block Diagram of Circuit Configuration.

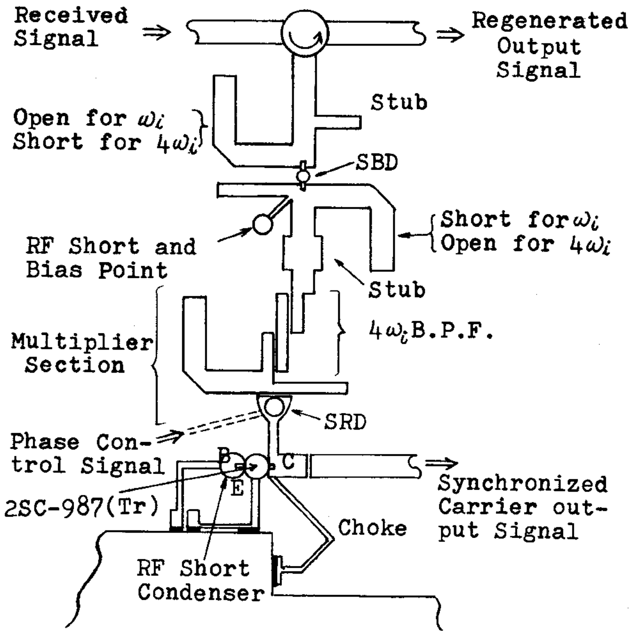

Fig.3 Circuit Configuration of Phase Coherent Parametric Mixer formed on dielectric substrate, excluding phase detector.

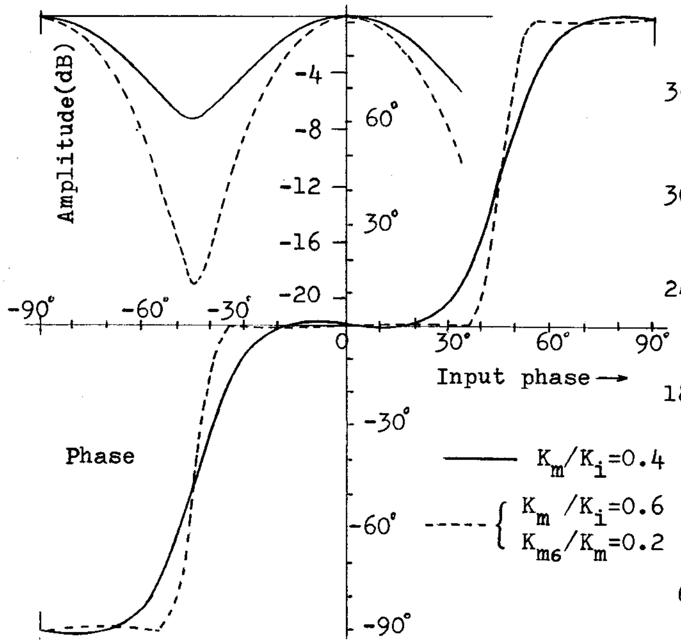

Fig.2 Calculated Phase and Amplitude Characteristics.

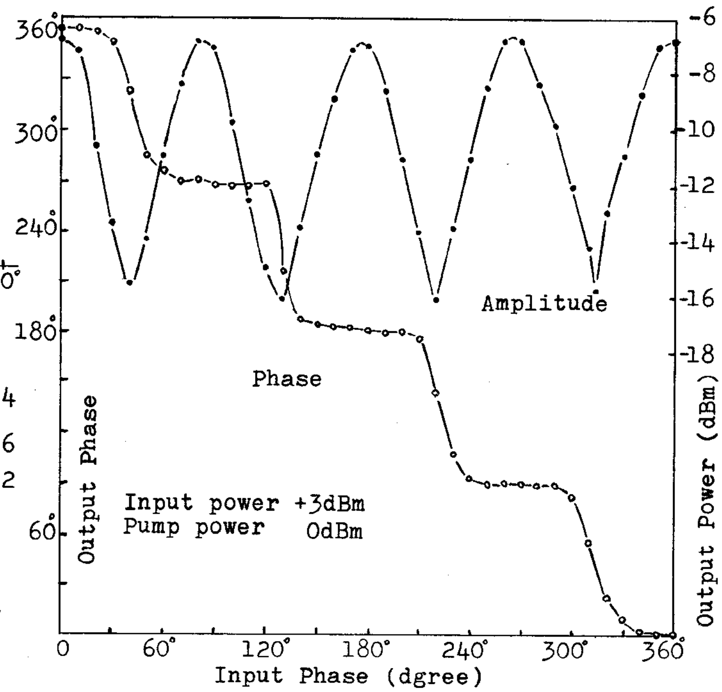

Fig.5 Obtained Phase and Amplitude Characteristics.

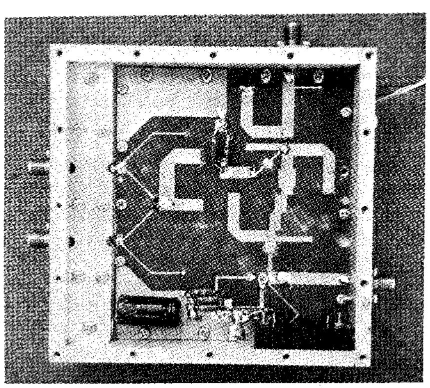

Fig.4 Phase Coherent Parametric Mixer manufactured for trial.

Fig.6 Phase Synchronization of VCO to a gated (on-off) input signal. 50nS/div.