PHASE SYNCHRONIZATION OF DIGITALLY MODULATED BURST CARRIERS IN TDMA SYSTEMS - A TECHNOLOGY OVERVIEW

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ABSTRACT

Time division use of the radio spectrum has created new multiple access techniques involving transmission of bursts of digitally modulated carriers using phase shift keyed modulation. Such systems are known as TDMA and involve burst carriers incorporating data rates from kilobits to gigabits per second. In order for these digitally modulated bursts to be demodulated at a terminal remote from the transmitter or source, it is necessary to provide a means to "recover" carrier frequency and phase from the received burst in order to be able to operate a coherent receiver. This paper will discuss the types of carrier burst synchronization techniques now in use, including the use of preambles to each burst which contain modulation by unique bit words which can be used to phase synchronize the receiver demodulator oscillator on a burst-to-burst basis. This paper will discuss the new microwave techniques of multipliers, tracking filters, anti-hangup resonators, which can be used to accomplish this synchronization for data rates from 40 Mbps to 1.6 Gbps.

Introduction

The technique of phase synchronism of a remotely located phase-locked oscillator by phase information transmitted periodically in a modulated carrier is not new. It is used in color television where a few cycles of the reference phase of a 3.58 MHz color subcarrier is transmitted immediately following the horizontal sync pulse. This reference phase carrier is then guted out and used to synchronize the color or chrominance oscillator of the color tv receiver to demodulate the color information transmitted in the raster line following that horizontal sync pulse. This function is now an established technique in millions of color tv receivers all over the world. The development of burst phase synchronization technology for world-wide color television during the 1950's produced subsequent systems in industry in which control of remote systems could be performed by reference bursts of carriers in which a further implementation was made by the modulation of the burst by unique bit words for improved recognition or for control or identification. However, it was not until the 1960's that the search for improved multiple access techniques for more efficient utilization of a communication channel led to the use of time division rather than frequency division (FDMA) of information and TDMA (time division multiple access) became seriously considered as a viable alternative to FDMA. In the 1970's, TDMA became operational in both the MARISAT system and the Canadian TELSAT system, and is now undergoing field trials in the INTELSAT system. TDMA is also undergoing tests in Japan with the Japan Communication Satellite (CS) for experimental purposes and in Europe with the Orbiting Test Satellite (OTS) by the European Space Agency.

TDMA communications is characterized by bursts of digitally-modulated carriers which occur in a frame. In the INTELSAT system, for example, each frame is 750 μsec long and up to 16 bursts, each representing a different user, can be accommodated in each frame. In present experimental and operational TDMA systems, quadrature phase shift keying (QPSK) is used at rates from 1 Mbps to around 1 gigabit per second and the QPSK modulated burst representing a particular user is repeated once each frame. If the receiver at the other end of the communication path is of the coherent type, it must be capable of demodulating the succession of bursts from that particular user by a phase detector driven by a phase locked oscillator which is synchronized for each burst by information included in a preamble at the start of that burst. The technology for synchronization of a phase-locked oscillator on a burst basis, rather than a continuous basis, has undergone much development during the decade following the first TDMA proposals and tests in the 1960's, and this paper is intended to highlight this development.

Burst Formats

Burst transmission is used as a multiple access technique wherein time rather than frequency is used to accommodate a variety of users. The receiver in the burst transmission system sees a continuing sequence of transmission bursts from different transmitters with the phase from one burst to the next being entirely random. Fig. 1 shows the technique of including a preamble preceeding each data burst in TDMA which uses the frame and burst format shown in Fig. 2. As indicated, each preamble which contains around 50-70 symbols (100-140 bits for QPSK) includes a first sequence of the carrier modulated 30 symbols which are used for carrier recovery (CR) and bit timing recovery (BTR). During this sequence, the phase of the local oscillator is brought into synchronism so that the remaining bits in the burst can be demodulated (see Fig. 3) and the clock rate or bit timing can also be recovered. A critical sequence of bits in the phase modulated carrier in a period following the carrier recovery period is the station identification code (SIC) which is used to activate the digital circuits and memories of the receiver for whom the SIC is intended so that the data bits in the burst can be processed. The preamble also usually includes a unique word for measuring bit error rate, and as shown in Fig. 2, an orderwire sequence which is used for both teletype (TTY) and voice communications. The 10-symbol unique word following the CR/BTR sequence can be used to establish the timing of frame or of the burst.

The preambles shown in Figures 1 and 2 and described in greater detail in References 1 and 2, provide accurate phase synchronization in a very short period of time; i.e., around one microsecond for 60 bits in the CR/BTR period for a 40-60 megabit system, following a guard or slack time of 100-200 nanoseconds to prevent overlap with the end of the preceeding burst. The number of bits used in the preamble is very small compared to the total number of bits represented in the burst. This total number will depend on the number of bursts transmitted in the frame and the traffic in each burst. As pointed out by Gabbard and Kaul (1), if a frame length of 750 microseconds were used with 15 accesses and 150 bits of overhead each, at 60 Mbps transmission rate, the total overhead to information bits per frame would be 2,250/45,000. The resulting percentage of overhead to total bits per frame is five percent, and the transmission efficiency is 95 percent. The total time allocated to guard time would be 15 times 150 nanoseconds, or 2.25 microseconds per frame, amounting to only 0.3 percent of the total frame time.

The Carrier Recovery System

The carrier reconstruction circuit (3) must produce a reference carrier which is used to demodulate two phases of a QPSK signal as shown in Fig. 4. This reference carrier is recovered from a signal which contains no discrete spectral component at the carrier frequency since in QPSK modulation the carrier is sufficient. A nonlinear device must, therefore, be used to regenerate the reference carrier, followed by a filter and by a frequency control circuit to compensate for frequency shifts in the system. Two different types of nonlinear devices are used; i.e., the times-4 multiplier, and the remodulator. The demodulator X4 multiplier, as described by the author in Reference 3, is a 4th law nonlinear device which regenerates a carrier component at 4 times the carrier frequency as indicated in Fig. 5 and implemented in Fig. 6. The X4 multiplier is followed by a filter and a limiter, and a frequency divider system such as that shown in Fig. 4 to recover the original input frequency. Two types of noise are encountered at the output of the X4 multiplier; pattern noise is derived from the modulation in the carrier and transformed additive noise is due to the nonlinear circuit. These cause phase jitter of the recovered carrier which can produce uncorrectable errors in the demodulation of the unique words and SIC following the acquisition time which can cause the TDMA system to fail for that burst. Thus, burst transmission of the TDMA variety requires consideration of preamble length and SC/BTR word length which results in inefficient transmission of information for too long a preamble, but for a shorter time allowed for the demodulator to recover the carrier and bit timing, the more the phase jitter of the recovered bit streams (data) and the poorer the performance of the TDMA system. As a result, a compromise between carrier acquisition time and recovered carrier phase jitter is required. See References 4 through 7.

One type of filter system which was developed for noise suppression and frequency and phase compression to minimize phase jitter is the use of a tracking filter following the X4 multiplier as shown in Fig. 7 based on a circuit developed by S. Yokoyama, et al, (6) and analyzed by M. Asahara, et al, (7). This circuit is now used for TELSAT TDMA. This circuit is different from the conventional phase lock loop system and is relatively free from hang up (8) making fast and stable acquisition possible. M. Asahara has analyzed the tracking filter to provide the transient phase error curves of Fig. 8, showing the reduced acquisition time by increasing loop gain. Fig. 9 shows the relative performance of the TELSAT version of Fig. 7 showing acquisition within CR/BTR time of T_1; by using a Q of 70 for the steady state, S. Yokoyama, et al, achieved an overall phase error of around 2 degrees for the recovered carrier at the end of the CR/BTR word leading to only 0.2 dB degradation in system C/N performance. The remodulator approach to carrier recovery, due to F. Gardner, uses a circuit of the type shown in Fig. 10. In this circuit, the nonlinear operation is performed on the demodulated signal by limiters following the demodulator. The data streams produced by the limiters are then applied to a remodulator to which the incoming modulator is also applied. The output of the remodulator is a reference signal with additive noise and pattern noise which is filtered, limited, and used as the reference carrier, which is also applied to the demodulator. No phase lock loop is used. Fig. 11 shows curves for phase jitter of reference carriers, due to F. Gardner, as produced by comparable X4 multipliers, remodulators and X4 multipliers, and an absolute value device such as a baseband restifier showing the improved performance of the remodulator and X4 multiplier system.

References

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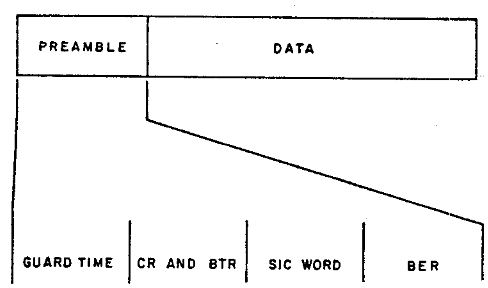


Fig. 1 Typical Preamble Structure Preceeding a Data Burst. CR (Carrier Recovery), BTR (Bit Timing or Clock Recovery), SIC (Station Identification Code)

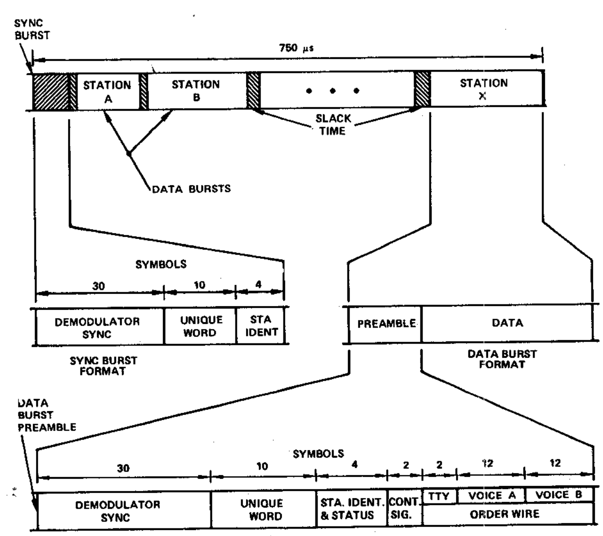


Fig. 2 TDMA Frame and Brust Format. According to W. G. Schmidt

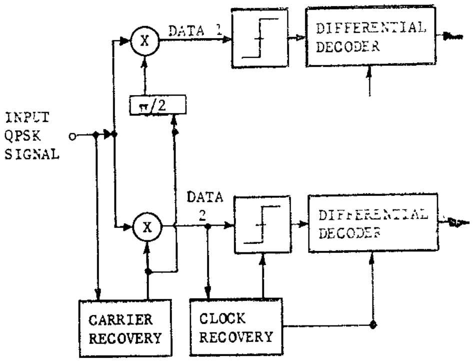


Fig. 3 Coherent QPSK Demodulator

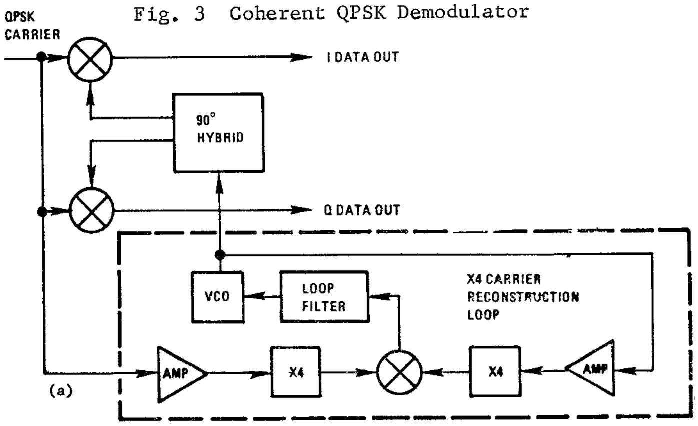


Fig. 4 Carrier Reconstruction Loop Circuit and QPSK Demodulator for QPSK Using a X4 Multiplier

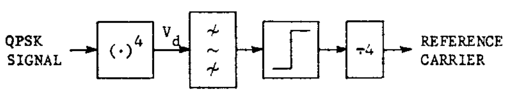


Fig. 5 Basic Carrier Recovery Circuit Using X4 Multiplier

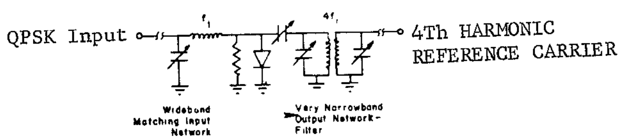


Fig. 6 X4 Multiplier Using Step Recovery Diode

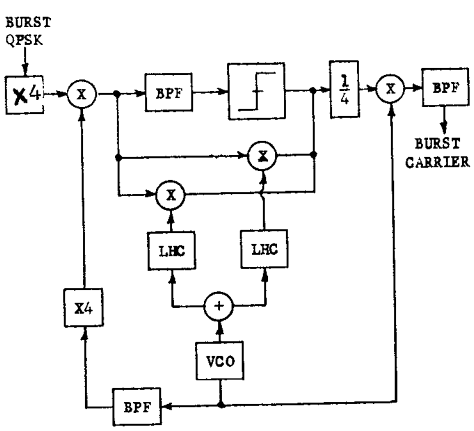


Fig. 7 Carrier Recovery Circuit Using Tracking Filter Following the X4 Multiplier

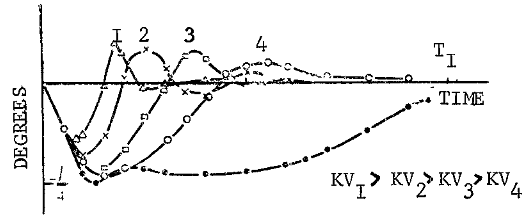


Fig. 8 Transient Phase Error of Circuit of Type in Fig. 7 Showing Effect of Various Loop Gains (KV) Due to M. Asahara

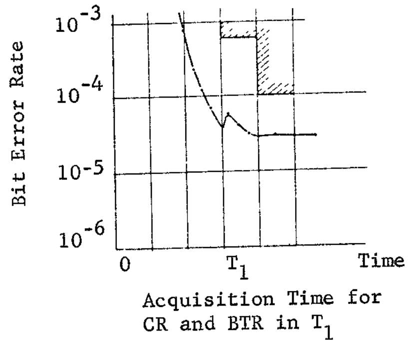


Fig. 9 Typical Acquisition Performance of System of Fig. 7

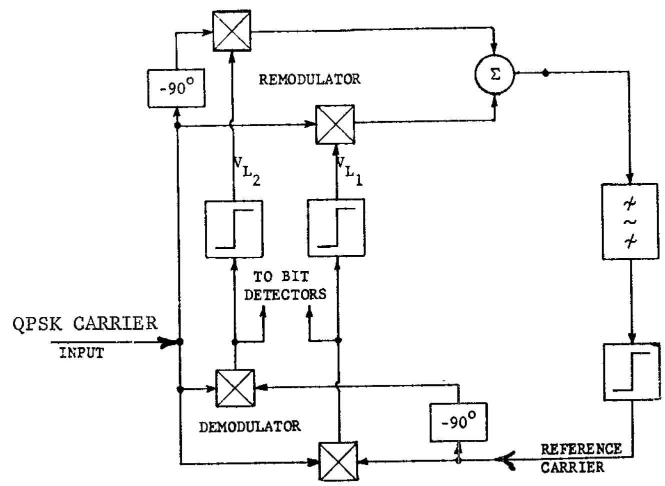
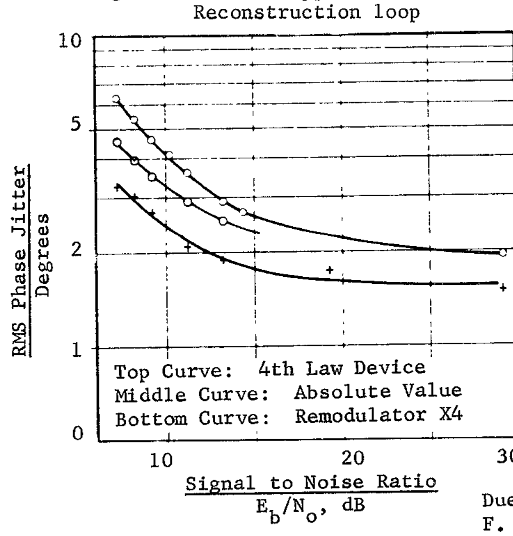


Fig. 10 Gardner Type of Demod-Remod Carrier Reconstruction loop



Due to F. Gardiner

Fig. 11 Phase Jitter of Reference Carrier with Single-Tuned Filter. BT = 0.07