Synchronous TDMA Direct Satellite Broadcasting Network

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Abstract— **A new direct satellite broadcasting network is proposed to solve a fundamental problem with existing DSB network. The conventional DSB networks are of a very centralized structure; the broadcasting station is limited to a central station which transmits all broadcast channels signals to the satellite. Direct broadcast from multiple sites in remote areas is impossible. This tight centralized structure of the DSB networks tends to bring about impoverishment of the broadcast contents and premature saturation of the market.**

In the proposed DSB system multiple stations located anywhere within the satellite coverage area can directly transmit signals to the satellite transponder shared in a synchronous TDMA mode and the combined signal from the satellite can be received with existing DSB receivers. Normally up to 10 stations can share a transponder for standard TV broadcasting. The transmit stations are small with 1.2-2.4m antennae. Direct live reporting from the event sites with SNG vehicles will be also possible. Thus the proposed system provides a truly direct satellite broadcasting for the transmit side as well as the receive side. The proposed system can realize a universal nationwide broadcasting network for the general public, integrate remote areas with national networks and open a new information age in the 21st century.

1. Introduction

In Japan, the number of subscribers for SkyPerfecTV has saturated at 4 million, which is only 10% of the potential market. A major cause of this premature saturation of the market is, in my opinion, the monopoly of the service provider and limited location of the transmit stations. The service provides for the DSB through CS (communication satellites) have merged to a single company and all transmit stations exist in Tokyo area. In order to conduct live broadcasting from a remote area, it is necessary to establish a long distance access link from the remote site to the satellite feeder station (FES) in Tokyo, which is time-consuming and expensive. The long distance link can be provided by a satellite link, but the double hop satellite links also double the signal transmission cost.

Considering those problems, it will be essential to develop a new system that enables direct broadcast transmission to the satellite from multiple sites anywhere and reception of the signals with conventional DSB user terminals existing everywhere within the coverage area of the satellite. This paper presents such a system based on Synchronous TDMA technology.

2. Synchronous TDMA and Its Application to DSB Network

In digital DSB systems a number of different channels signals are multiplexed in time division multiplex (TDM) mode to form Transport Stream (TS) for transmission to the satellite. Thus all signals can be transmitted from a single station and can be received anywhere within the coverage area of the satellite. This central structure of the network does not enable direct transmission from multiple sites and strictly limits the application fields of the network to conventional, one way and one-point-centric broadcasting. .

In Time Division Multiple Access (TDMA) system a number of Feeder Earth Stations (FES) can transmit signals to the satellite from anywhere within the coverage area of the satellite. Each station transmits a burst of finite time length to the designated time slot on the satellite. In order to avoid collision of bursts from different stations, each station must conduct burst timing control. The burst timing control method is classified into two types; asynchronous and synchronous. In the asynchronous system given are Guard Time (GT) of a few symbols before and after each burst and the burst timing control is made to contain the burst within the GT. The timing error can exceed a few symbols so long as the burst is contained within the GT. In the Synchronous TDMA system, on the other hand, all bursts are fully synchronized within a limited phase error of the symbol clock hence no guard time greater than half a symbol is required. In synchronous TDMA all signals are fully synchronized and look as if sent from the same station hence the signal can be received with conventional DSB receivers everywhere. Table 2-1 gives a list of some satellite TDMA systems.

Table 2-1 Parameters of various TDMA systems

System Developed period Organization	Frame length Data rate Synch/Async	Notes
SMAX 1967-72 NTT Public Corp.	125 (μsec) 13.664(MHz) Synch.	Verified feasibility of Synch TDMA
K band TDMA 1974-82 NTT Public Corp.	328 (μsec) 64(Mbps)BPSK Synch.	Back-up for 8 RC stations in Japan
Remote Is. TDMA 1974-82 NTT Public Corp.	105 (μsec) 105(Mbps)QPSK Synch.	192 telephony & 2 TV chs to Ogasawara Is.
Intelsat TDMA 1975-84 Intelsat	2 (ms) 120(Mbps)QPSK Asynch.	International Gateways
Others	All others developed in Japan, Europe, USA and Canada adopted Asynchronous methods.	
DSB TDMA 2003— proposed .by the author	30 (ms)(TVframe) 42.192(Mbps) QPSK(DVB-S) Synch.	This proposal

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3. Basic Specification of the Proposed System

3-1. Link Power Budget

Table 3-1 shows an example of power link budget for Japan. Similar parameters apply to many satellite systems in the world with similar sizes of coverage areas.

Table 3-1 Link Power Budget

Item	Specification		Notes
Uplink			
FES			
-HPA Output (dBW)		13	20W
-Antenna Gain (dBi)		43	1.2m(d), Eff.;60%
-Feeder loss (dB)		0.5	
-EIRP (dBW)		55.5	
Propagation Loss (dB)		207	14 GHz
Satellite			JCSAT-4
-G/T (dB/K)		10	
-Boltzman Constant.(dB)		-228.6	
Uplink C/No (dB/Hz)		87.1	
Downlink			
Satellite			
-Transponder P. (dBW)		18	75W
-Antenna gain (dBi)		37	Eff.1/2
-Feeder loss (dB)		0.5	
-EIRP (dBW)		54.5	
Propagation loss (dB)		206	12 GHz
Receiver	UT	FES	
-G/T (dB/K)	10	17	Ant.d(m) 0.5/1.2
-Bolzman Constant. (dB)		-228.6	
Downlink C/No (dB/Hz)	87	94	
Overall C/No (dB/Hz)	84	86.3	
Data Rate (dB.Hz)		75.0	30 Mbps
Eb/No (dB)	9.1	11.3	
Operation Eb/No (dB)		5.0	
Link margin (dB)	4.1	6.3	

3-2. Earth Stations and User Terminals

The link power budget allows the following sizes of the FES (Feeder Earth Station) and UT (user terminal)

FES ; - Antenna with 1.2m diameter
- HPA saturation power at 700W
- Transmitter Power Margin; 13,7 (dB)

UT ; - Conventional DSB receiver (G/T= 10 dB/k)

3-3. TDMA Frame structure

The multiplex format in the proposed system follows DVB-S specification. The following is an example set of parameters.

[1] Frame period ; 30 (ms) (TV frame freq.; 29.97 Hz)

[2] Data rates;

(1) Modulation ; 42.192Mbps

(2) Information (Mbps); 29.2 (Puncture ratio 3/4)

[3] An example of TDMA frame

Number of packets per frame ; 648 (1,410,048 bits)

Frame frequency ; 29.92 (Hz)

[4] Burst format

(1) The burst is composed of multiples of 8 packets ; processing unit for FEC and randomization.

(2) The first packet starts with a fixed pattern to assist the receiver pull in process,

(3) Some bits of the final 12 packets can not carry information data because of interleave processing. But they can be used for inter-ES communication.

4. Satellite Loop Clock Synchronization

4-1. TDMA Signal Multiplex on the Satellite

Multiple Feeder Earth Stations (FES) send data bursts signals to a common satellite transponder. The signals are combined on the satellite to form a single sequence for the downlink signal. The bursts timing is controlled to avoid collision with the bursts from other FES. One of the earth stations is designated as a reference earth station (RES). The RES transmits a reference burst which defines the TDMA frame. Then each FES transmits its data burst to the assigned time slots on the TDMA frame. The combined frame is depicted in the following figure.

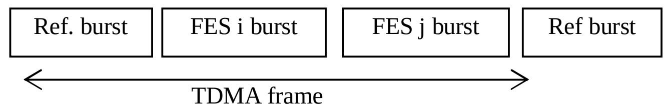


Figure 4-1 An example of TDMA frame format

4-2. Clock Synchronization System

Every FES must synchronize its transmit clock with the RES clock on the satellite. The downlink signal then becomes a clock coherent signal. The FES receives the downlink signal which contains all bursts from all the earth stations. The FES regenerates the RES clock from the receive signal by receive phase lock loop (Rx PLL). The recovered RES clock gives the clock reference at the FES. The FES compares the phase of its own burst clock with the clock reference. The detected phase error is then smoothed by Loop Filter and control the transmit clock generating voltage controlled oscillator (Tx VCO). The output of Tx VCO is used to generate the transmit burst signal to be sent to the satellite. The transmit phase lock loop (Tx PLL) contains the long satellite loop delay hence must be of a very narrow bandwidth for loop stability. The structure of the clock synchronization system is depicted in Figure 4-2.

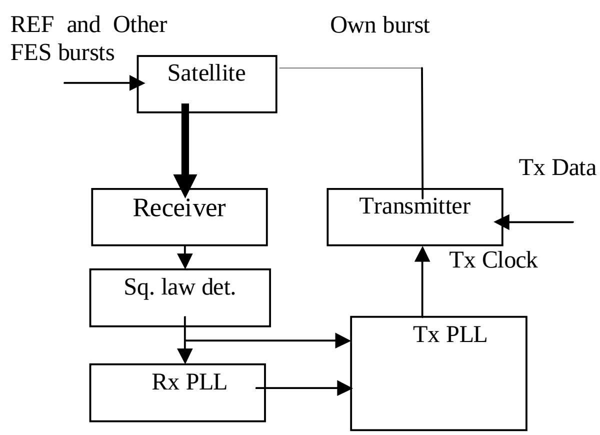


Figure 4-2 Configuration of Clock Synchronization System

4-3 Rx PLL

The amplitude of a QPSK modulated signal changes with the modulating signal, hence a square law detector can regenerate the clock components as depicted in Figure 4-2. The Rx PLL can be a continuous or sample & hold type PLL. The continuous type PLL regenerates the Rx Clock which is locked to the average phase of the receive signal. The sample & hold type PLL is externally supplied with a sample pulse that tells the end timing of the RES burst, hence can regenerate the RES Clock. The bandwidth of the Rx PLL is designed at BL=3 Hz, which is 1/10 of the frame frequency. As the input signal bandwidth is around 30 MHz, there is about 70 dB bandwidth gain. There is about 10 dB degradation at the square law detector, hence the total S/N improvement is about 60 dB. The sample & hold type PLL has an additional degradation from sampling, which is about 10 dB, if the minimum burst length is 1/10 of the frame, resulting in total S/N improvement of 50 dB. Even when the input S/N is 0 dB, the Rx PLL output S/N becomes 50 db; (the variance of) the phase error is only 0.13 degree.

4-4. Tx PLL

The structure of Tx PLL is depicted in Figure 4-3. Tx PLL is a sample & hold type PLL. The externally supplied sample pulse tells the end timing of its own burst. The phase comparator output is sampled by the sample pulse to select the phase error information of its own burst against the reference clock. The Tx PLL contains the satellite loop which has about 0.27 second delay.

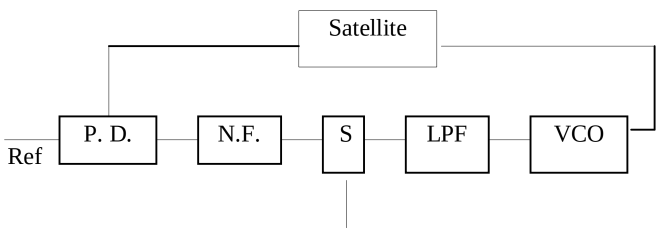


Figure 4-3 Structure of Tx PLL

Based on the previous works [1],[4], the following loop parameters are adopted;

Loop parameters;

Natural frequency	;	$\omega n = 0.924$ (rad/sec)
Damping factor	;	$\zeta = 0.707$
Equivalent noise bandwidth	;	BL= 0.49 (Hz)
Loop gain	;	Ko = 290 (/sec)
LPF time constant	;	To = 340 (sec)
Satellite Loop Delay	;	$\tau = 0.27$ (sec)

Loop stability;

The Bode diagram analysis on the Tx PLL with the above parameters gives the following margins;

Phase Margin	; 43 (degrees) at $\omega / \omega n = 1.4$
Gain margin	; 12 (dB) at $\omega / \omega n = 19.0$

VCO Phase Noise

For such a narrow band PLL, the resultant phase error is dominantly caused by the phase noise within the VCO. The phase noise is characterized by phase noise power density spectrum $/\phi(j\omega)/^2$ which generally has the following components..

$$/\Phi(j\omega)/^2 = \alpha/2Ba + \beta/\omega^2 + \gamma/\omega^3$$

The first term is the additive noise component with bandwidth Ba and the total phase noise power α, the second term is the random walk noise and the third is 1/f noise components.

Another frequently used characterization of the oscillator phase noise is the average phase drift over time τ, which is defined as follows. Let the phase of the oscillator ϕ(t), then the average time drift $\Delta\phi(\tau)$ is defined as $/\Delta\phi(\tau)/^2 = <\{\phi(t) - \phi(t-\tau)\}^2>$, where <x> means the time average of x.

It can be shown that the above two expressions are related as follows;

$$/\Delta\phi(\tau)/^2 = \alpha + \beta.\tau + \gamma.\tau^2$$

The frequency stability function S(τ) of an oscillator with frequency fo is defined by

$$S(\tau) = \Delta\phi(\tau) / (2\pi \text{fo}.\tau)$$

For large τ, the phase drift is dominantly caused by 1/f noise and the frequency stability of the oscillator tends to be constant;

$$S(\tau) = \sqrt{(\gamma)} / (2\pi \text{fo})$$

Tx PLL phase error

It can be shown the resultant phase error in PLL with damping factor $\zeta = 1/\sqrt{(2)}$ is given by the following formula;

$$/\phi e/^2 = \alpha + 3\beta/16/BL + 9\gamma/128/BL^2$$

The phase noise performance of crystal oscillators today is quite good. For example, a commercial VCXO (ex. 7100 series , NDK) gives the following performance

$$/\Phi(j\omega)/^2 = -50 \text{ (dBc/Hz) at 1(Hz)}$$
$$= -80 \text{ (dBc/Hz) at 10(Hz)}$$

which gives

$$\gamma = 2.5 \times 10^{-3}$$
$$\beta < 4.0 \times 10^{-5}$$

Then the resultant phase error of Tx PLL with BL = 0.49 (Hz) is

$$/\phi e/ = 0.027 \text{ (rad)} = 1.57 \text{ (deg)}$$

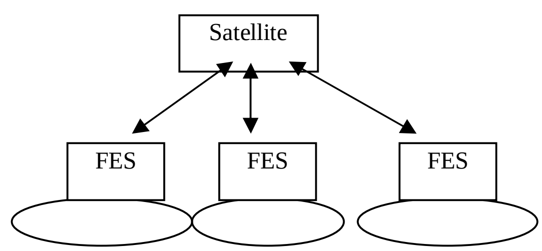
Thus a very accurate synchronous TDMA is technically feasible.

5. Social benefits of the Synchronous TDMA DSB network

In Europe a system with the same objective as this proposal has been successfully in operation. The **SkyPlex**[3] system provides direct broadcast from different countries for all over Europe. However, the Skyplex system requires a special, complex satellite with capability of onboard demodulation of uplink SCPC signals and re-multiplexing them to DVB-S TDM formats for the down link. On the other hand the Synchronous TDMA DSB requires only a bent type satellite, hence is applicable all over the world.

The proposed system can provide a universal broadcasting for the wide areas covered by the satellites. It will be effective to vitalize the local industry and develop national economy. The broadcasters may evolve to BSP corresponding to ISP in the Internet to provide the public access with the nationwide broadcast networks.

The FES can also work as a Gateway for the local networks. A satellite system with a 27MHz transponder can provide 700 telephony and 2 TV channels over a wide area covered by the satellite. The system concept is depicted in the following figure.



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[4] D.Kumagai, H.Doi, M.Takada, " SMAX-PCM Multiple Access Satellite Communication System" Journal of IEICE vol. 53, No. 2, 1970 (in Japanese)