Paper No. 83036
IEEC & E '83

A SIMPLE AND RELIABLE TECHNIQUE FOR INTEGRATED VOICE-DATA COMMUNICATIONS

Session No. 3

G. Benelli, V. Cappellini, E. Del Re and R. Fantacci
Istituto di Elettronica - Ingegneria and IROE - C.N.R.
Via Panciatichi, 64 - 50127 Firenze, Italy

Integrated voice-data techniques are presented to transmit simultaneously an audio signal and data on the same communication link, in particular for assuring a data-link between an aircraft and a ground station by using the usual VHF-UHF analog communication link. Different modulation techniques are considered (as AM-PSK, AM-MSK) and simulation results are reported to select the higher efficiency technique for practical applications.

Introduction

Integrated voice-data communication techniques are of high interest for many applications where an audio signal and data are to be transmitted simultaneously on the same communication link, both for bandwidth reduction and for utilization of existing analog systems also with data transmission. An important application, which is mainly considered in this paper, is represented by the data-link between an aircraft and a ground station by using the usual VHF-UHF analog communication link.

Indeed the present organization of air traffic control (ATC) is based almost completely on the voice communications between the pilot and the ground station. The control station keeps the status of the airways updated and regulates the whole system, communicating with all the aircrafts in its control area. [1,2] Communications with transoceanic or transcontinental flights are generally performed using HF bands (presenting in some cases a poor propagation). In metropolitan areas, VHF and UHF bands are generally utilized. These bands allow a good communication quality, even though they can be utilized only over limited distances. Moreover, the channels available in these bands are often saturated due to the high density of air traffic, as in terminal areas, especially at some peak hours. This fact often determines delays in departure and arrival of flights, decreasing also the safety level of air traffic.

A solution to the above problem for the next future is represented by the introduction of a digital channel for the automatic transmission of a significant part of the data and information, that are currently transmitted by voice to and from the aircraft. However a simple and economical solution of high actual interest is represented by the integrated voice-data transmission on the available communication link, without great modifications to the present equipments for voice transmission (very attractive for small aircrafts).

In the following integrated voice-data techniques are presented, in particular to solve the above air traffic control problems. Different modulations techniques are considered and simulations results are reported.

Integrated Voice-Data Communication Systems

The coexistence of voice and data in a single channel of a communication link can be achieved in various ways : by means of multiplexing with frequency or time division; by orthogonal modulations. The second approach is here followed.

In the developed systems voice signal and data modulate the same carrier: the voice modulates the amplitude of the carrier, while the data modulate the phase or the frequency of the same carrier. The general block diagram of these systems is shown in Fig. 1.

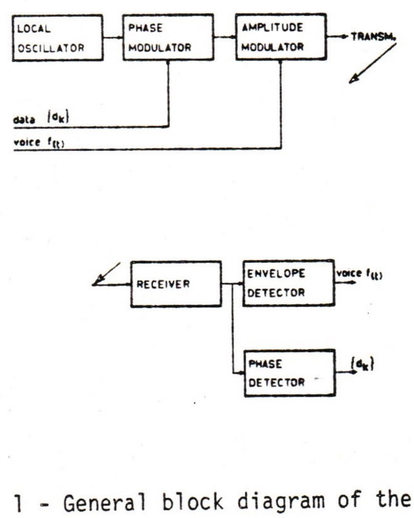

Fig. 1 - General block diagram of the developed systems.

83CH1955-4 REG7/0078 $01.00 © 1983 IEEE

The carrier $A\cos(\omega_0 t + \theta)$, generated by a local oscillator, is first modulated in phase by the data sequence $\{d_k\}$ and therefore is of the form

$$s_1(t) = A\cos\left[\omega_0 t + \phi(t) + \theta\right] \quad (1)$$

where

$$\phi(t) = \sum_{k=-\infty}^{\infty} d_k g(t - kT) \quad (2)$$

d_k being the k-th information symbol and $g(t)$ being the phase pulse depending on the particular considered modulation.

The signal is then sent to an amplitude modulator, which modulates the amplitude of the carrier by the voice signal $f(t)$. The signal at the output of the AM modulator is

$$s(t) = A\left[1 + mf(t)\right]\cos\left[\omega_0 t + \phi(t) + \theta\right] \quad (3)$$

where m is the amplitude modulation index.

A signal modulated in phase by means of a PSK modulation has a constant envelope. Nevertheless, because of the abrupt discontinuities present in a PSK signal, and hence the considerable extent of its spectrum, when that signal passes through a finite-band system, the envelope of the modulated wave is no longer constant. [3,4] These envelope variations are decreasing the efficiency of the considered communication systems, because they introduce a distortion which interferes with the voice signal (such a distortion of course depends on both the transmission rate and the modulation index). Therefore it is convenient to utilize phase or frequency modulations, which require less bandwidth: FSK and MSK modulations are hence considered in the following for data transmission, in comparison with PSK modulation.

Modulation Techniques

A binary phase-shift-keying (BPSK) signal has the form

$$s_B(t) = \sqrt{2E}\cos(\omega_c t + \Psi_k) \quad (4)$$

with $kT \leq t \leq (k+1)T$, k integer, where ω_c is the carrier angular frequency, T the bit time interval and E the signal mean power. If a_k is the binary data sequence to be transmitted, $a_k = \pm 1$, we have

$$\Psi_k = 0 \qquad \text{if } a_k = -1 \quad (5)$$

$$\Psi_k = \pi \qquad \text{if } a_k = 1 \quad (6)$$

Further the spectral power density of a PSK baseband signal is given by [5]

$$G(\omega) = T\left\{\frac{\sin[(\omega T)/2]}{(\omega T)/2}\right\}^2 \quad (7)$$

Spectral occupancy is considerable, due to the sharp phase changes of the signal. A similar behaviour is presented by a four-level PSK (QPSK); however such a modulation can be more interesting with respect to BPSK, because it allows a higher data rate.

An interesting modulation technique for the considered application is represented by the minimum-shift-keying (MSK). [4,6] MSK is a particular modulation technique, having the following properties:

1) the envelope of the modulated signal is constant (as for PSK);

2) the instantaneous frequency deviation is $\pm$ 1/4 of the bit rate;

3) the instantaneous phase is continuous and varies linearly by $\pm\pi/2$ during every bit interval;

4) spectral extension is very little, if compared with other digital modulations with the same transmission rate (therefore the signal tolerates also severe bandpass filtering without great degradation in the performance).

The MSK signal can be expressed as [3]

$$s_M(t) = \sqrt{2E}\cos(\omega_c t + \frac{\pi}{2T} a_k t + x_k) \quad (8)$$

with $kT \leq t \leq (k+1)T$, k integer, where a_k are the binary data to be transmitted and the x_k terms are determined for phase continuity as

$$x_k = x_{k-1} + (a_{k-1} - a_k)k\frac{\pi}{2} \quad (9)$$

with $x_0 = 0$ and therefore $x_k = 0$ or π (module 2π).

The spectral power density of an MSK baseband signal is given by

$$G(\omega) = \frac{4\pi^2 T\left[1 + \cos(\omega T)\right]}{(\omega^2 T^2 - \pi^2)} \quad (10)$$

having a spectral extension quite lower than that of PSK modulation.

The frequency-shift-keying (FSK) modulation is a well known technique, having characteristics

- for several view-points - intermediate between PSK and MSK modulations. [5]

Simulation Results

The performance of the communication systems described above was evaluated through a computer simulation. The equivalent baseband model of the systems was utilized to reduce the computation time.

The bandpass filters in the communication chain were modelled as Butterworth filters with the following characteristics

- transmitter filter: fourth order, with -3 dB single-side bandwidth 7.5 kHz;
- receiver filter: eighth order, with -3 dB single-side bandwidth 5 kHz.

Filtering was performed in the frequency domain, while other operations, such as modulation and demodulation, were simulated in the time domain. The transformations from one domain to the other were done by using the Fast Fourier Transform (FFT) algorithm. Further the signal was processed in blocks of 2048 samples, the sampling frequency being 19200 Hz.

In order to estimate the distortion introduced by the data signal and the phase modulation, the signal at the output of the AM detector $f_1(t)$ is compared with the original signal $f(t)$, which modulates the carrier amplitude. An error signal

$$e(t) = f_1(t) - f(t) \tag{11}$$

is therefore obtained. The simulation program gives some parameters relative to this error signal. First, the mean noise power N_0 of this error signal is computed and expressed in dBm, taking as reference a disturbance of 1 mW. Denoting with S the power of the signal $f(t)$, the signal-to-noise ratio S/N_0 is then evaluated. Another interesting parameter is the maximum value e_p of the error signal, i.e. the peak error, which indicates the maximum error which can be encountered in the communication system. In the following, the peak error is always expressed as a percentage of the maximum value of the modulating signal $f(t)$. All these parameters are obtained by supposing the communication channel as a noiseless channel: in this way the error signal is due only to the interferences of the data with the amplitude modulation.

To characterize the influence of the amplitude modulation on the data, the bit error probability P_e at the data demodulator is evaluated. In this case the communication channel is assumed to introduce an additive Gaussian noise, having a power density N.

Four different signals, modulating the voice channel (representing a typical behaviour of voice), are utilized in the simulation:

1) a tone at 937.5 Hz frequency;
2) a tone at 1875 Hz frequency;
3) an addition of five tones as given by

$$f(t) = \sum_{i=1}^{S} Q_i \cos\left[2\pi i(468.75)t\right] \tag{12}$$

with the coefficients Q_i as $Q_1 = Q_3 = 2/9$, $Q_4 = Q_5 = 1/9$;

4) a real voice signal having a time duration of 4 s.

The simulation with the previous signals was carried out for several values of the AM modulation index m.

The noise power N_0, the signal-to-noise ratio S/N_0 and the peak error e_p are reported in the Figs. 2, 3 and 4, respectively for the first three modulating signals as a function of the data transmission rate v_s. In these Figures a, b and c refer to amplitude modulating signal represented by a tone at 937.5 Hz, 1875 Hz and the addition (12), respectively (with m = 0.8).

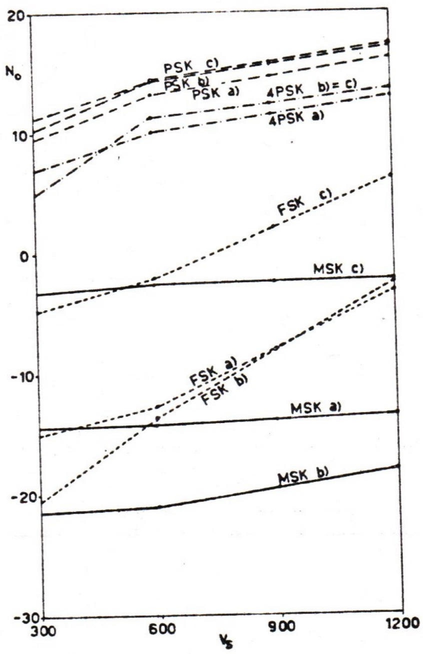

Fig. 2 - Noise power N_0 as a function of the data transmission rate.

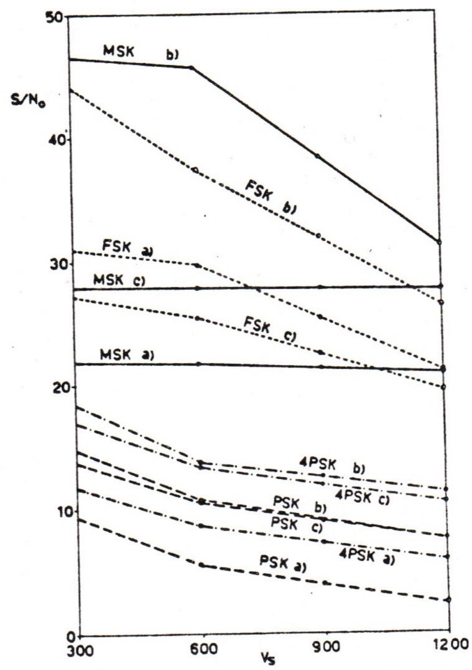

Fig. 3 - Signal-to-noise ratio S/N_0 as a function of the data transmission rate v_s

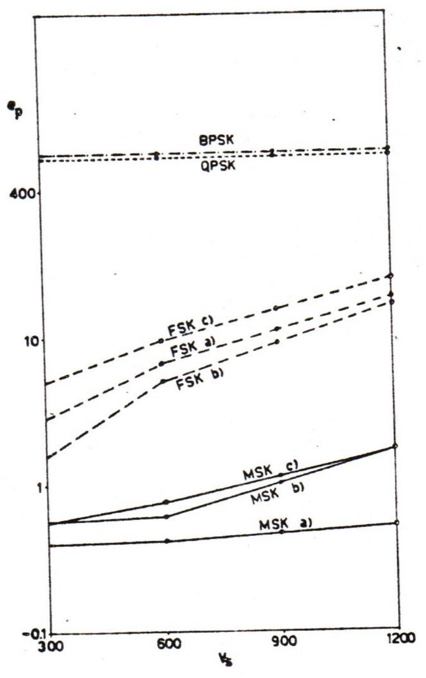

Fig. 4 - Peak error e_p as a function of the data transmission rate v_s.

In Fig. 5 the signal-to-noise ratio S/N_0 is shown as a function of the data transmission rate v_s, when the amplitude modulating signal is the real voice signal (with m = 0.9).

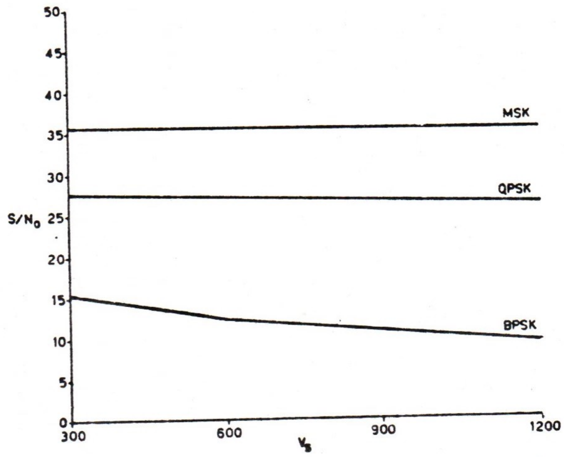

Fig. 5 - S/N_0 as a function of v_s (real voice)

From these results it is clear that BPSK systems often present poor performance: the S/N_0 can be lower than 15 dB (minimum acceptable level for air traffic data link); peak errors quite greater than the maximum value of the amplitude modulating signal can arise. QPSK systems show a slight efficiency improvement.

FSK and particularly MSK systems present higher efficiency: for instance AM-MSK modulation gives S/N_0 greater than 30 dB with $e_p < 1°/\circ$ in almost all cases. Therefore the AM-MSK system results to be the most suitable for integrated voice-data communications as in the aircraft-ground data links.

References

1. W. L. Ashby, "Future demand for air traffic services", Proc. IEEE, vol. 50, n. 3, 1970.
2. P. R. Drouilhet, "DABS: a system description", Lincoln Laboratory, ATC 42, FAA-RD-74-189, 1974.
3. L. J. Greenstein, P. T. Fitzgerald, "Envelope fluctuation statistics of filtered PSK and other digital modulations", IEEE Trans. Communications, vol. COM-27, n. 4, pp. 750-760, 1976.
4. D. H. Morais, K. Feher, "The effects of filtering and limiting on the performance of QPSK, offset QPSK, and MSK systems", IEEE Trans. Communications, vol. COM-27, n. 8, 1976.
5. G. Benelli, G. Borghi, V. Cappellini, E. Del Re, S. Gueli, "Combined amplitude-phase modulation for a VHF communication link", in Proc. IEEE Inter. Conf. on Communications, Denver, 1981.
6. S. A. Gronemeyer, A. L. McBride, "MSK and offset QPSK modulation",IEEE Trans. COM-27,8,1976.