MICROPROCESSORS IN DISTRIBUTED BROADCAST RADIO SYSTEMS

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ABSTRACT

Microprocessors are incorporated in several hardware features of a patented new system which uses the wasted power inherent in standard AM Broadcast Radio transmission. This unique system can be used for many applications. The first large-scale demonstration of the capabilities of the system was conducted for the purpose of electrical demand limiting by utility companies. In these trials, control signals were sent to several hundred receivers to shut-down equipment during times of peak load on the utility grid. The receivers for this system were low-cost and microprocessor operated. They were placed over a wide area, up to 175 km from the transmitter, which in these trials was a high-power (50kW), standard AM broadcast station. Control signals did not interfere with the quality nor the reception range of the broadcast station's audio signal. Data reception by the system receivers had error rates under 1%.

INTRODUCTION

It is a well known phenomenon of standard AM radio that the information contained within the signal is utilizing less than 50% of the power transmitted. This is because the carrier contains at least 50% of all the transmitted power while containing no signal. In addition, to avoid intermodulation distortion, the broadcast of a single sinusoidal tone can be done with a maximum efficiency of only 33%. However, the presence of carrier signal allows

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the AM radio receiver to be of very simple design and therefore of very low cost. Given this broadcast system and its inherent information inefficiency, a system has been developed which uses part of the broadcast energy to send data signals simultaneously with the audio signals of the AM broadcast station. To do this, several conditions had to be met:

1) The additional signal could not interfere with the AM broadcast and vice versa.

2) The signal had to be reliably received at sufficient data rate for the application.

FCC authorization to use the broadcast band for this new system was received under these conditions. The first application was electric utility load management. Control signals were sent to several hundred receivers to shut down equipment during times of peak load on the utility grid.

Figure 1 is a block diagram of the distributed broadcast system components. Microprocessors are important elements in design of the receivers, but also are the major functional components of the control console and transmitter-modulator. The processors provide very flexible data and command entry to the system and do all code conversion and interface control.

THEORY

The approximate and stylized power spectrum of the typical broadcast band radio station is shown in Figure 2. It is seen that sidebands within 150 Hz of the carrier are very small. The signal for standard AM is

$$S_{AM}(t) = (A_c + f_s(t))\cos w_c t \tag{1}$$

neglecting the arbitrary phase of the carrier. This signal has a power spectrum of

$$\begin{aligned} F_{AM}(w) = {} & \frac{\pi A^2_c}{2}(\delta(w-w_c) + \delta(w+w_c)) \\ & + 1/4(F_s(w-w_c) + F_s(w-w_c)) \end{aligned} \tag{2}$$

where F’s are the Fourier transforms of the autocorrelation functions of the signals. If $f_s(t)$ were a simple sine wave,

$$f_s(t) = A_s \text{ Cos } w_s t \tag{3a}$$

and

$$S_{AM}(t) = (A_c + A_s \cos w_s t)\cos w_c t \tag{3b}$$

then

$$F_{AM}(w) = \frac{\pi A^2}{2}{}_c(\delta(w-w_c) + \delta(w + w_c)) \quad \text{(carrier)} \tag{4a}$$

$$+ \frac{\pi A^2}{8}{}_s(\delta(w-w_c-w_s) + \delta(w-w_c+w_s) \tag{4b}$$

$$+ \delta (w + w_c + w_s) + \delta (w + w_c - w_s)) \quad \text{(sidebands)}$$

The power is found from

$$\text{Power} = 1/2\pi \int_{-\infty}^{+\infty} F_{AM}(w)\, dw = A^2{}_c/2 \quad \text{for the carrier} \tag{5}$$

$$= A^2{}_s/4 \quad \text{for the sidebands}$$

A_s cannot be larger than A_c to avoid modulation distortion. Therefore, the maximum power in the sidebands is $A^2{}_c/4$ or 1/3 of the total power output of the AM broadcast channel sending a pure sine tone.

From Figure 2, it is tempting to view the large carrier power and empty bandwidth of approximately +/- 150 Hz surrounding the carrier and devise some system to make use of this power and unused bandwidth. The system under discussion, devised by Altran Electronics, has demonstrated such use of the power and bandwidth using a phase modulation of the carrier signal.

A phase modulated signal can be written as

$$S_{pm}(t) = A_c \cos(w_c t + f_p(t) + \theta) \tag{6}$$

Again, if $f_p(t)$ is a simple sine wave, to illustrate, the signal

$$S_{pm}(t) = A_c \cos(w_c t + A_p \sin w_p t) \tag{7}$$

ignoring arbitrary phase θ.

The autocorrelation of this signal is

$$R_{pm}(T) = A^2{}_c/2 \sum_{n=-\infty}^{+\infty} J^2{}_n(A_p)\cos(w_c + nw_p)T \tag{8}$$

where $J_n(A_p)$ are the Bessel functions of variable A_p of n’th order.

The Fourier transform or power spectral density is

$$F_{pm}(w) = \frac{\pi}{2} A_c^2 \sum_{n=-\infty}^{+\infty} J^2{}_n(A_p)(\delta(w-w_c-nw_p)+\delta(w+w_c+nw_p)) \qquad (9)$$

When both standard AM and PM signals are present on the same carrier, the combined signal is

$$S_{am+pm}(t)=(A_c + a_s \cos w_s t)(\cos(w_c t+A_p \sin(w_p t)) \qquad (10)$$

The Fourier transform of the autocorrelation of this combined signal is then the power spectral density of this combined signal. This expression uses simple sine wave modulation for illustration and also ignores arbitrary signal and carrier phase angles.

The combined signal can be rewritten as

$$\begin{aligned} S_{am+pm} &= A_c \cos(w_c t + A_p \sin w_p t) \\ &\quad + A_s \cos w_s t(\cos(w_c t + A_p \sin w_p t)) \end{aligned} \qquad (11)$$

The first part of this expression is similar in form to (7), the PM waveform with a spectral density given by (9). It can be seen that by adjusting A_p and w_p , this first part of the power spectrum of the signal, equation (11), could neatly fit within the unused broadcast radio bandwidth. The second term of S_{am+pm} , (11), is similar in form to the second term of (3b) with a power density given by an expression very similar to (4b) with $w_c t + \sin w_p t$ taking the place of $w_c t$. This leads to the expression for the remaining part of the power spectral density of (11) as

$$F_{am+pm} = \frac{\pi}{8} A^2{}_s \sum J^2{}_n(A_p)(\delta(w-w_s-w_c-nw_p) \quad + \qquad (12)$$

$$\delta(w - w_s + w_c + nw_p + \delta(w + w_s - w_c - nw_p) +$$

$$\delta(w + w_s + w_c + nw_p))$$

These spectral components are within the baseband of the audio program. If A_p were very small, $J_o \cong 1$

and $J_n \cong 0$ for $|n|>0$. Equation (12) would then reduce to (4b), the standard AM sidebands. If, for example, A_p were approximately $\pi/6$ radians and w_p were 20 x 2π radians per second,

$J_0 (.5) = .9385$
$J_1 (.5) = .2423$
$J_2 (.5) = .0306$
$J_3 (.5) = .0026$
$J_4 (.5) = .0002$
J_n ’s are very small for all $n > 4$.

The effect at 20 Hz of the phase-data spectrum within the baseband may be found by experiment to be unnoticable to the listeners of the audio broadcast program. The criteria needed to determine what phase modulation spreading the baseband spectrum causes audible distortion needs further investigation and depends not only on electronic and communication theory but also on the discriminatory powers of the human auditory system.

A narrow-band phase detection receiver designed to detect the signal $\frac{\pi}{6} \cos 2\pi(20)t$ would find from (9) that total power in this signal is given by

$$\text{Power} = 1/2\pi \int_{-\infty}^{+\infty} F_{pm}(w)\,dw = \frac{A^2_c}{2} \sum_{n=-\infty}^{+\infty} J^2_n(A_p)$$

and since $J^2_n (a_p) = 1$

$$\text{Power} = A^2_c /2,$$

the same power as existed in the carrier in the case where there was no PM modulation. Similarly, from (12), the sideband power is $A^{2}{}'_s /4$. If A_s and A_c were equal, as in the case of the largest possible sine wave modulation before distortion, the PM signal would represent 67% of the power transmitted. Of that total, 12% of the power would be in the PM sidebands close to the carrier.

CONCLUSION

The distributed broadcast system described here is capable of using the power left unused in the transmission of standard AM stations. The capability of a receiver to receive data by PM detection is largely due to the high power of the signal being detected. It is, in fact, on the order of twice as powerful as the baseband audio signals. Error of signal detection in this data system is affected not only by data rates of this transmission method, but also by the inherent phase jitter of the broadcast transmitter and the limitation imposed upon the size and waveshape of the PM signal modulated on the broadcast carrier.

Determination of the optimum data signal wave-shape, modulation index and modulation frequency without interference to the audio baseband AM signal needs further investigation. In addition, the limitations on the rate of data transmission with this system are still dependent on the acceptable error rate. Applications allowng larger error can, as usual, allow higher data transmission rates.

This theoretically sound framework for this system by no means made it a practical operating system. Other unique features are also incorporated, made possible by microprocessor and integrated circuit technology and by microcomputer software.

Additional applications of this system are numerous and await exploitation by potential end users and broadcast station operators.

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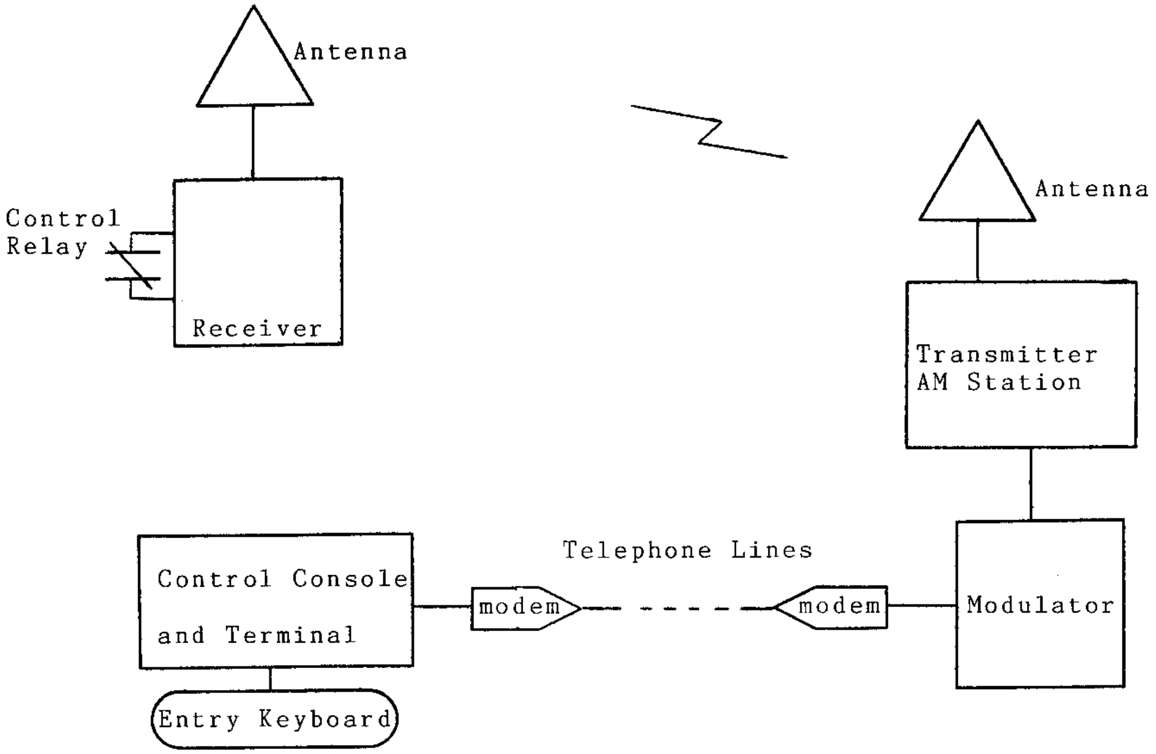

Figure 1. Distributed Broadcast System Components

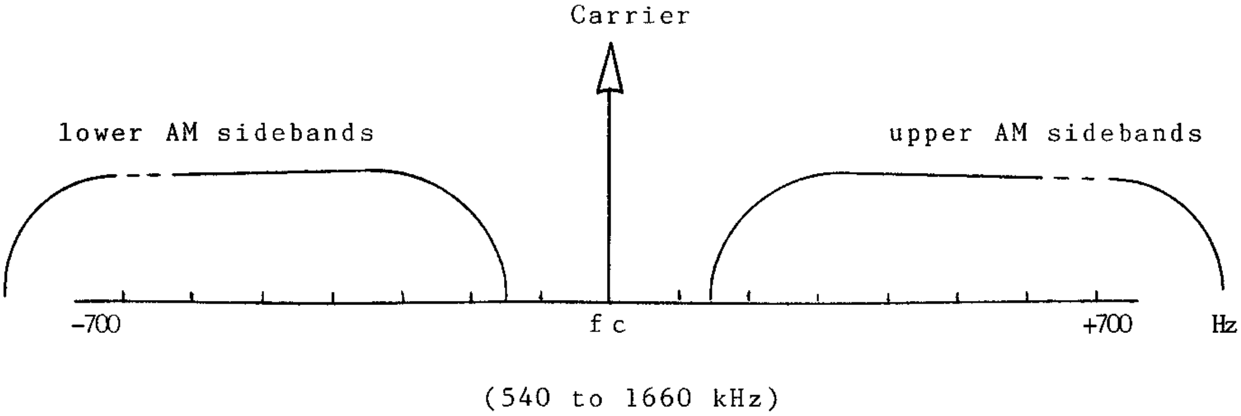

Figure 2. Approximate and stylized power spectrum of typical broadcast band radio station