

Dual Antenna Diversity System for FM Reception

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ABSTRACT

This paper investigates the performance of digital implementation of dual antenna phase diversity system utilizing the Constant Modulus Algorithm (CMA) and Maximal Ratio Combiner (MRC) and proposes a two -antenna CMA/MRC hybrid algorithm for mobile FM reception. Simulation proved that CMA has superior performance in frequency selective multipath (long-delay) with medium and strong signal conditions. On the other hand, the MRC optimizes the Signal-to-Noise Ratio (SNR) output in weak signal conditions. The signal conditions are constantly changing in mobile environment, therefore the appropriate algorithm should be chosen dynamically to optimize signal reception.

CITATION: Shatara, R., "Dual Antenna Diversity System for FM Reception," *SAE Int. J. Passeng. Cars – Electron. Electr. Syst.* 6(1):2013, doi:10.4271/2013-01-0165.

INTRODUCTION

The primary purpose of a diversity system is to improve reception performance under multipath conditions. A diversity system employs two or more uncorrelated receiving antennas. Diversity reception in mobile communication systems has been reported in the literature [1,5,6,7,8,9,10] to reduce audio distortion due to fading. It is a well-known fact that Maximal Ratio Combiner (MRC) is used to reduce flat fading but incapable of reducing distortion from selective fading. Lab and field testing verified that the performance of the Constant Modulus Algorithm (CMA) is superior to that of MRC in medium and strong signal levels where frequency selective multipath dominates. In weak signal conditions, the CMA assumption becomes poor and the MRC is a reasonable alternative due to its valid assumption for all signal conditions. MRC maximizes the Signal-to-Noise Ratio (SNR) output and reduces amplitude fades significantly. This paper proposes a new hybrid algorithm that utilizes CMA and MRC for multi-antenna FM system.

MOBILE PROPAGATION CHANNEL REVIEW

The propagation channel for mobile reception can be classified into two general categories. The first is fading over long distances traveled, which is referred in the literature as large-scale fading [11,12]. In large scale fading the primary channel impairments are free space path loss and shadowing. The second category is fading over short distances, which is referred to as small-scale fading. In small scale fading the channel impairments are primarily due to reflections and

scattering from objects. If the channel provides a line-of-sight path then the small-scale fading is said to be Rician because the variations of the voltage envelope of the carrier have statistics that are characterized by the Rice probability density function (PDF). If no LOS path exists then the variations of the voltage envelope of the carrier have statistics that are characterized by the Rayleigh PDF.

It should be noted here that the terms **large-scale** and **small-scale fading** refer to effects that happen over large and small distances respectfully. The reader should not assume that large-scale means large signal fluctuations and small-scale means small signal fluctuations. In fact, in many cases the opposite is true. In a Rayleigh fading situation where there is no line-of-sight path and the reflectors are all relatively close together so that the various path length differences are short relative to the wavelength of the carrier, the signal fades can be very dramatic; on the order of 40dB over distances of a few meters (for FM). Large-scale fading on the other hand generally refers to situations where distances traveled are in kilometers such as driving away from a city or driving behind a mountain. In general large-scale fading and small-scale fading occur simultaneously.

Figure 1 shows the effects of large-scale fading due to path loss and shadowing. The trace labeled small-scale fading shows the effects of fades that happen over short distances. Note that there is still large-scale fading present in the small-scale fading trace.

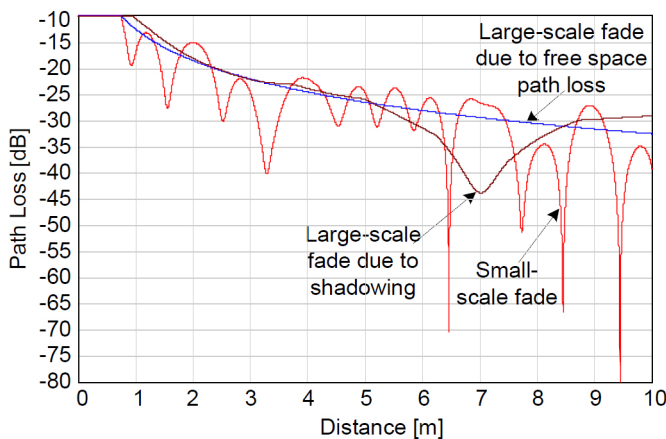


Figure 1. Plot of carrier signal amplitude envelope voltage as a function of distance traveled. Large-scale fading due to path loss and shadowing is evident. Small-scale fading is shown superimposed on the large-scale fading

CONSTANT MODULUS ALGORITHM REVIEW

Combining (controlled summation) signals from multiple antennas offers the advantage to control the directionality of the antenna system. A gain toward the desired signal and a null toward the undesired can be achieved in the antenna pattern (i.e. two-antenna system). In the case of FM broadcast, multipath rays (interferers) can potentially be suppressed by creating a null in the antenna pattern in the direction of the multipath interferer.

For narrowband modulation, antenna combining is accomplished by adjusting the amplitudes and phases of the individual antenna signals prior to summation. The gain and phase applied to each antenna signal are equivalent to complex weighting in the complex baseband model and are referred to as simply the antenna or combining 'weights'. The weights are continuously adapted (adjusted) to optimize certain reception performance metrics.

The method of determining the combining weights varies with the application, but the case of mobile reception of broadcast FM is particularly challenging because the combining must be adapted as the vehicle moves. The adaptation is 'blind' (no cooperation from the transmitter), and the signal is analog (signal imperfections are difficult to mask). A characteristic of FM modulation is that the modulated waveform has constant modulus (amplitude) as shown in Figure 2, which provides prior knowledge about the transmitted signal [2-3].

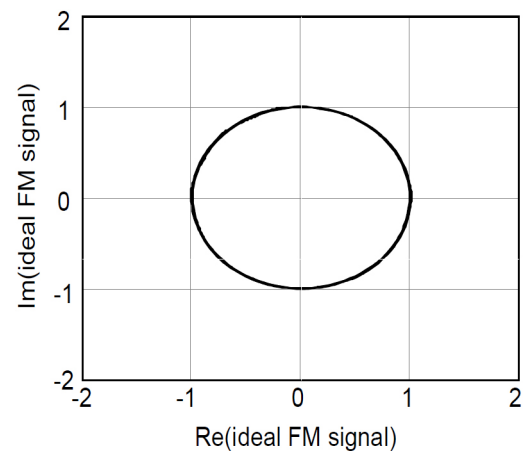


Figure 2. Ideal FM complex baseband signal

However, in a multipath reception environment, the received signal no longer possesses this constant modulus property because of flat or frequency selective fading. Thus the complex baseband signal trajectory is no longer a circle but a complicated spiral pattern as shown in Figure 3. This provides information about the reception environment that can be used to determine the combining weights. The CMA is an efficient algorithm that allows adaptation of the diversity system parameters based on amplitude variation of known constant amplitude signals. For the two-antenna case with a direct and single delayed reflection, which is under consideration here, it is always possible to position a null in the direction of a single multipath interferer. Note that for an incident plane wave, only the phase of the received signal will differ between the two antennas and hence combining weights can always be found such that the signals cancel in the combined output. However, while this solution does in fact satisfy the constant modulus constraint, it does not guarantee that the CMA algorithm will adapt to this solution and, in general, the CMA solution is not unique. For example, the null could be placed in the direction of the direct path instead of the reflected path and still satisfy the CMA constraint.

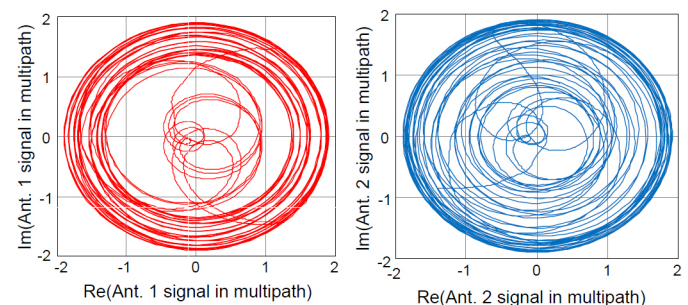


Figure 3. FM Complex baseband signal in multipath

Figure 4 shows a two antenna combining system with the diversity update block implemented in a Digital Signal Processor (DSP). The system requires two front ends.

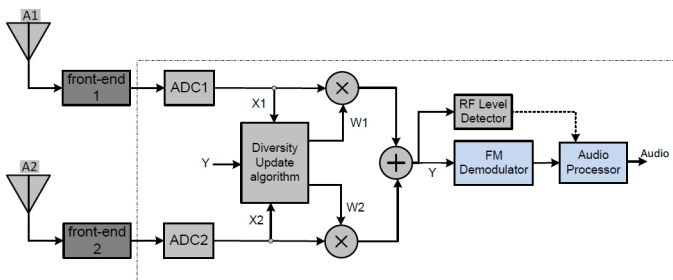


Figure 4. Two-antenna diversity combining system

Because the CMA cost function is phase invariant, any ‘rotation’ of a solution yields another solution, which is equally as good, and hence the CMA solution is inherently non-unique, see [Appendix](#) for the CMA algorithm details. The particular solution to which the algorithm converges will depend on the initial value of the weights and will tend toward the ‘nearest’ solution. While this ambiguity could be resolved by further constraining the solution, this degree of freedom tends to improve the transient behavior by allowing convergence to a solution that is nearest the current state (minimum time solution). The CMA solution restores the constant modulus (CM) property of the signal as shown in [Figure 5](#).

Figure 6 shows a simple simulation of the performance of dual antenna CMA algorithm in frequency selective multipath environment. A significant distortion reduction in the demodulated signal tone is observed. (Simulation parameters: 1 kHz tone, 75kHz deviation, amplitude ratio between desired to undesired is 0.9 and 20μsec time delay difference. Refer to [Appendix](#) for the two-ray model). [Figure 7](#) shows scope snap shot of an actual dual antenna CMA system output. It correlates very well with the computer simulation.

The CMA is a simple algorithm to implement in DSP, however it has undesirable behavior in weak signal conditions where other undesired signals (co-channel and weak receiver spurious products) might exist in the Intermediate Frequency (IF) filter passband. The following two undesirable behaviors have been observed in the field:

- The CMA “latched” onto a spur in the passband that had higher amplitude than the desired signal. The listener experienced audio disturbance, including mutes!
- In co-channel signal conditions, the CMA exhibited a hysteresis of “latching” back-and-forth between the desired and undesired signals.

One method is to limit or reduce the above CMA undesirable issues is by reducing the adaptation step size factor μ_{CMA} (see [Appendix](#)) in weak signal conditions, until the performance is satisfactory. A second method is to switch

to a “default” antenna and stop the CMA diversity. In either case, it defeats the purpose of using diversity! In addition, the CMA assumption is not derived to maximize SNR where the opposite is true for the MRC case.

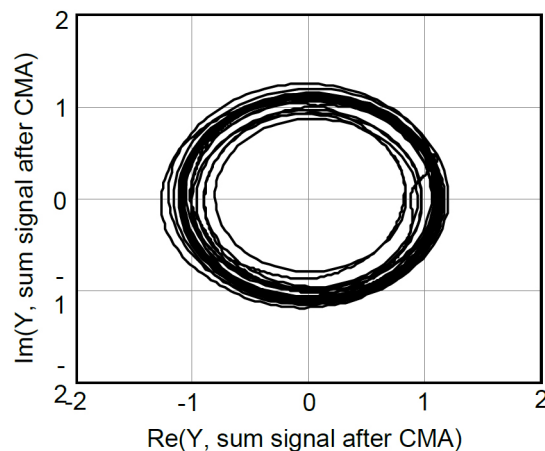


Figure 5. Output Y of CMA

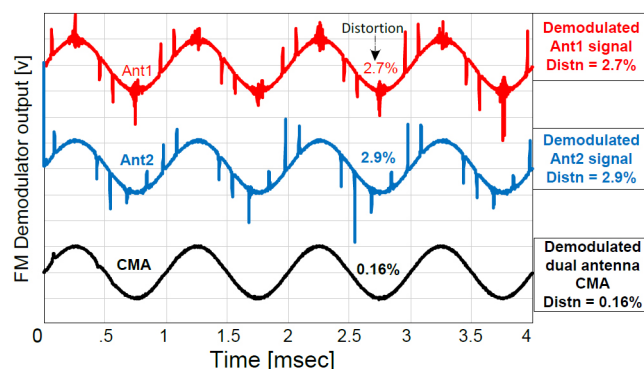


Figure 6. Simulated FM Demodulator output signal of Ant.1, Ant. 2, and dual antenna CMA

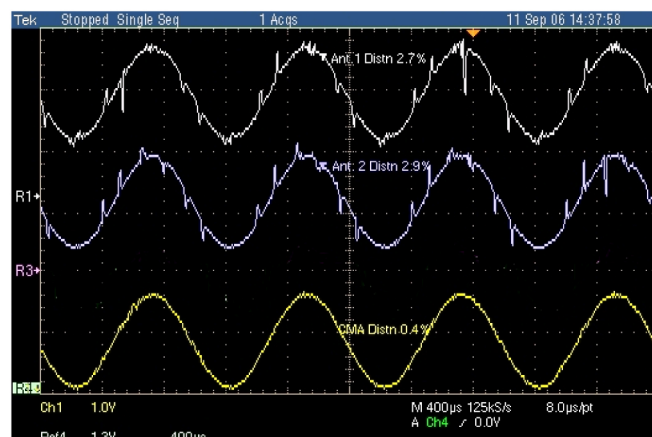


Figure 7. Actual dual antenna CMA system output displayed on the scope

MAXIMUM RATIO COMBINER REVIEW

The purpose of the MRC diversity is to reduce amplitude fading by means of optimizing the SNR at the output of the summer (refer to [Appendix](#) for MRC details). The MRC is a “natural switch”, it favors the antenna signal with higher SNR and it makes the stronger signal “stronger” and the weaker signal “weaker”. A simple simulation of a two-antenna MRC system illustrates the point. [Figure 8](#) shows independent (and uncorrelated) antenna signal amplitudes in addition to the resulting MRC signal amplitude. It can be realized that the MRC will favor the antenna signal with higher amplitude. In some cases, it completely favored antenna 2 signal over antenna 1 signal as shown.

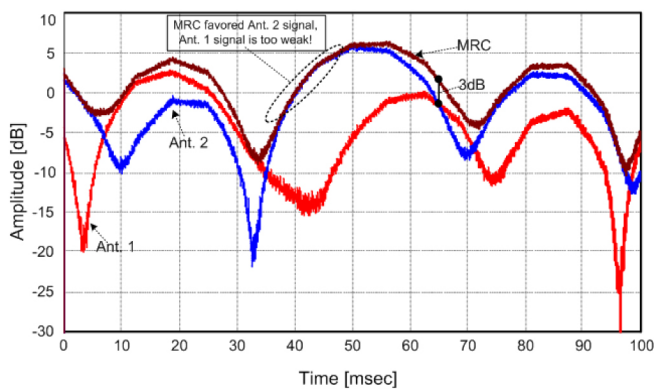


Figure 8. Simulation of uncorrelated Rayleigh fading received by Ant. 1 (red) and Ant. 2 (blue). The MRC result is also shown (brown)

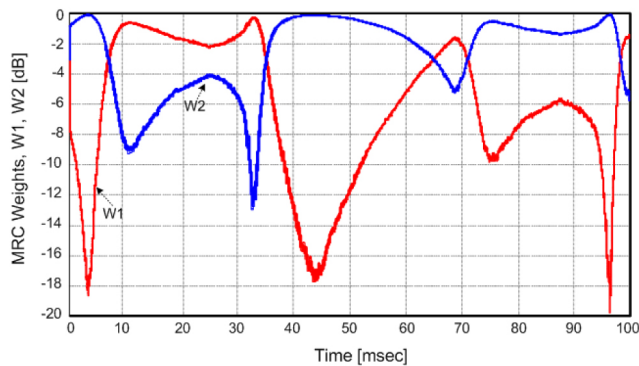


Figure 9. MRC weights (W_1 , W_2) are adapted to maximize signal amplitude

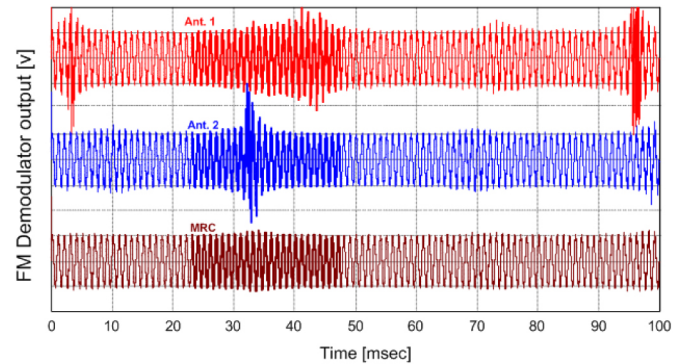


Figure 10. The demodulated FM signals of Ant. 1, Ant. 2 and MRC. Modulating tone = 1 kHz, Deviation = 75kHz

[Figure 9](#) shows the adapted weights which follow the antenna signal amplitudes as expected. [Figure 10](#) shows the FM demodulator outputs for Ant. 1, Ant. 2 and MRC signals. The fades in the MRC output are significantly reduced. The simulation was done with modulating tone of 1 kHz and 75 kHz deviation.

DUAL ANTENNA CMA/MRC DIVERSITY SYSTEM

The MRC/CMA algorithm block diagram is shown in [Figure 11](#). The hybrid technique optimizes diversity reception over a greater dynamic range of signal levels. While the CMA assumption becomes poor for weak signals, the MRC algorithm assumptions remain valid for all signal levels. Furthermore, while the CMA is generally superior to the MRC at high SNRs, the MRC algorithm outperforms the CMA for weak signals. An adaptation strategy is implemented that is substantially controlled by the CMA for strong signals and substantially controlled by the MRC algorithm for weak signals. The transition between the two algorithms is accomplished by controlling the weight of each algorithm's contribution to according to the received signal strength.

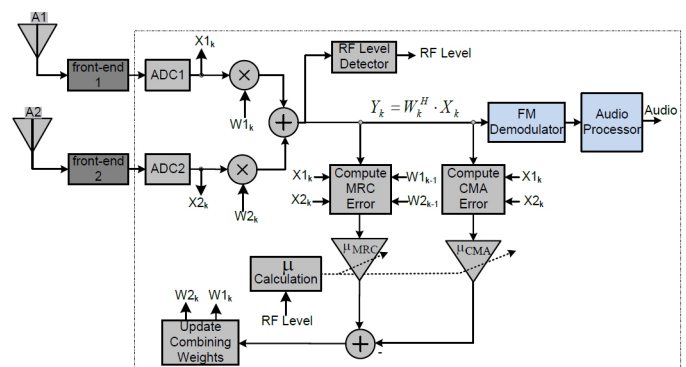


Figure 11. Hybrid MRC/CMA algorithm