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A. A PREDETECTION DIVERSITY COMBINER

Diversity reception has been used as a means of reducing the effect of fading in long-range communication. Brennan (1) has shown that a diversity system in which the various signals are combined as a weighted sum is generally superior to a switching diversity system in which the strongest signal is chosen and the weaker signals are discarded. The circuits devised by Kahn (2) and by Mack (3) combine signals after detection; these circuits fail to produce an optimum combined signal when the signal-to-noise ratios before detection fall below unity. The predetection combiner of Altman and Sichak (4) shifts the phases of the radiofrequency signals so that they add algebraically rather than vectorially, but their circuit does not weight the signals before combination in such a way that the signal-to-noise ratio of the combined signal is maximized.

The circuit that has been investigated here (5) combines before detection, and the signals are properly phased and weighted before combination. This circuit may be designed to produce an optimum combined signal even if the signal-to-noise ratios of the signals before combination are less than unity; it will fail only if the signal-to-noise ratio of the resultant signal after combination falls below unity. Since the signal-to-noise (power) ratio of the resultant signal is the sum of signal-to-noise ratios before detection, this circuit will show marked improvement over existing combiners when many weak signals are combined.

In describing the diversity combiner which is presently being investigated, we shall assume that the bandwidth occupied by the modulated signal is small compared with the reciprocal of the duration of the impulse response of any of the radio paths between the transmitting antenna and the various diversity receiving antennas. Selective fading may then be neglected. This condition is often encountered in scatter communication links and is necessary for the proper functioning of the combiner.

In the absence of selective fading, the signal emerging from any one of the diversity receiving antennas will be proportional to the transmitted signal, and we can regard the proportionality constant as the gain of the space path from the transmitter to that particular receiving antenna. Specifically, let the signal voltage applied to the transmitting antenna be

$$e(t) = \mathrm{Re}\left\{M(t)\, e^{j\omega_o t}\right\}$$

in which the complex time function M(t) describes the modulation. The vector signal received by the i^{th} receiving antenna is $M(t)\, K_i(t)$. The complex gain of the path to the

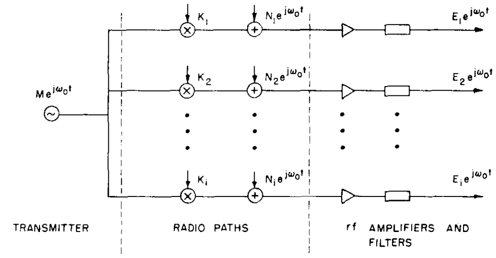

Fig. XVIII-1. Model of communication channel from transmitter to receiver.

i^{th} receiving antenna $K_i(t)$ varies slowly in time as the received signal fades. Noise will be received with the signal. If the vector $N_i(t)$ represents the noise received on the i^{th} receiving antenna, the noisy received signal is

$$E_i(t) = M(t)\, K_i(t) + N_i(t) \tag{1}$$

Figure XVIII-1 is a model of the communication channel described by Eq. 1. For convenience, the radiofrequency amplifier gains have been lumped with the path gains. If the amplifiers have identical gains, and if they are properly connected to the receiving antennas, we can assume (5) that the output noises are uncorrelated and have the same mean power:

$$\overline{N_i(t)\, N_k^*(t)} = \begin{cases} N_o^2 & \text{if } k = i \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

Let us consider a diversity combiner that produces as its output a weighted sum of the received signals

$$E_o(t) = \sum_i a_i(t)\, E_i(t) \tag{3}$$

We require appropriate weights, $a_i(t)$, that maximize the signal-to-noise ratio of the combined output. Such weights are found to be proportional to the conjugates of the path gains:

$$a_i(t) = A(t)\, K_i^*(t)$$

The same complex multipliers A(t) must be used for each term in the sum in Eq. 3. Thus, proper operation of the combiner hinges upon the ability of the circuit to obtain accurate estimates of the path gains. These are obtained by taking short-time averages

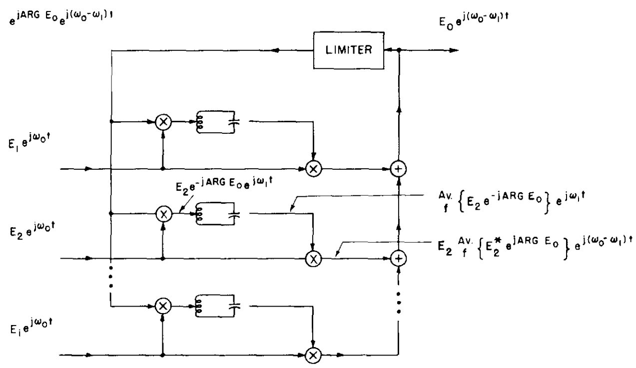

Fig. XVIII-2. Multipath model of the combiner.

of the measured-path gains, and by using crystal filters that have bandwidths comparable with the fading rate. The weights described by

$$a_i(t) = \underset{f}{\mathrm{Av.}}\left\{E_i^*(t)\, e^{j\mathrm{Arg}\, E_o(t)}\right\}$$

are convenient. The notation $\underset{f}{\mathrm{Av.}}\{\ \}$ describes the averaging performed by the crystal filters. Thus, the weighted sum in Eq. 3 produced by the combiner is

$$E_o(t) = \sum_i E_i(t) \underset{f}{\mathrm{Av.}}\left\{E_i^*(t)\, e^{j\mathrm{Arg}\, E_o(t)}\right\} \tag{4}$$

A block diagram of the circuit described by Eq. 4 is shown in Fig. XVIII-2.

Circuitry for a two-path model of the combiner is being designed and constructed in the laboratory. With this model we intend to investigate the behavior of the combiner when weak signals are applied and when the noises received with the signals have slightly different powers and are partially correlated. If the gains of the amplifiers connected with the different diversity receiving antennas are unequal, the amplified noises will have different powers; and, unless special precautions are taken (5), noise voltages received on closely spaced antennas will be partially correlated.

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References

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