A SUGGESTED METHOD FOR TRANSMISSION
OF DATA FROM ORDVAC
TO A SET OF CONTROLLED TARGETS (U)

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Copy 2 of 8 copies
Total pages 17
I. GENERAL CONSIDERATIONS

This report is a survey of the questions which arise when Ordvac's output signals are to be transmitted to any one of a set of planes, and received in a form which is understandable by a pilot (or acceptable by an autopilot). The functions which any output apparatus must perform, as well as those functions which it is desirable that it perform, are given first. It is then shown that a particular design satisfies these requirements.

The functions which must be performed are now listed.

1) Some means must be provided for putting the digital representations of the control signals, which Ordvac produces, into a form which can be transmitted over a communication channel.

2) Means must be furnished in each plane for selecting the appropriate control signal with high reliability.

3) The control signal, when received in the plane, must be put in a form which can be understood by a pilot, or acted upon by an autopilot.

Some additional and supplementary features seem to be very desirable. These features follow.

4) Bandwidth is at a premium, and a narrow bandwidth for the communication channel of (1) would be desirable. There are other advantages to using narrow bandwidths which will be discussed below.
5) Some means should be furnished of indicating, in the plane, that the control system is probably functioning properly.

6) The plane's ground position should be available to the pilot at all times. This information could serve as a check on the means furnished in (5), as well as furnishing data which would allow him to take proper action if the control system fails to function.

7) The equipment in the plane should be small, light and have low power consumption.

8) The electromagnetic radiation from the plane should be kept to a minimum for security reasons. Thus it would be desirable to use just a single way communication system.

The points will now be discussed, but not in order, since one of the most pervasive items is (4'), the bandwidth consideration. The primed listings are the counterparts of the unprimed ones.

4') It is shown first that an audio bandwidth (≤ 10 kc/sec) is sufficient to transmit all of the output data even when provisions are made for some error detection and correction.

/ number of ways of utilizing the audio bandwidth are then discussed.

One estimate of the rate at which the output data are to be transmitted may be obtained as follows. About 25 bits (7 bits for x*, 7 bits for y*, 7 bits for identity, and 4 bits

* No distinction is made here between smoothed, predicted, or observed quantities. The predicted values may be good ones to use.
for change of heading) are to be transmitted per plane in 15
sec. (the scan time of the radar). For 100 planes this yields
an average rate of ~175 bits/sec.

If the set of 25 binary digits is to be protected against
single errors, then

\[ 1 + (25 + m) = 2^m \]

or \( m = 5 \)

is the condition which must be satisfied by \( m \), the number of
check digits. If \( m + 1 \) digits are used, then double errors
can be detected, and single errors corrected. The total of
31 digits now corresponds to an average rate of ~210 bits/sec.

More elaborate checks may be considered, for example,
provisions for single error correction and double error
detection of each of the sub-messages, namely the ones for \( x \), \( y \)
identity, and change of heading. One now has a \( \frac{41}{4} \) digit message
to be transmitted to each plane, at an average rate of about
300 bits/sec. Further protection against errors may be obtained
by using a coding procedure such as that suggested by Gell-Mann
and Dancoff, or even of transmitting each message 3 times and
using a majority vote. Even for the \( \frac{41}{4} \) digit messages, and
triple transmissions, the average rate remains less than
1000 bits/sec.

Another class of estimates of transmission rates may be
formed by considering the proposed coding procedure for Ordvac.

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* R.W. Hamming "Error Detecting and Error Correcting Codes"
  BSTJ 29, 147 (1950).
A code for 100 planes is now being prepared; it has been estimated that with this code the set of 25 binary output digits per plane will be computed and appear someplace in Ordvoc no more often than once every 25 milliseconds. Thus one arrives at a maximum rate of \[
\frac{25 \text{ bits}}{25 \cdot 10^{-3} \text{ sec.}} = 1000 \text{ bits/sec.}
\]
when no additional digits are used for error correction or detection. If 31 digits are computed in the same time interval, then about 1300 bit/sec. is the maximum rate, and for \(\frac{1}{4}\) digit messages, one obtains a maximum rate of about 1800 bits/sec.

It should be remarked that 500 bits per second can be transmitted easily over an "ordinary" telephone channel and that about 1600 bits per second have been transmitted over such channels.* In general \(n\) pulses (corresponding to \(n\) bits) can be transmitted over a \(n\) cycle/sec. bandwidth using single sideband modulation, and \(n/2\) bits with double sideband modulation. Thus even for the maximum rate of 1800 bits/sec. (\(\frac{1}{4}\) digit messages) and for a system using double sideband modulation a 3600 \(\text{kHz}\) bandwidth is sufficient.

If the maximum rate is to be increased significantly, either by greater redundancy, or by shorter computation times, then it will be necessary either to use greater bandwidths, or an auxiliary memory. It will be assumed hereafter that an audio bandwidth will be used.

* See trip report of R.I. Hulsizer. M-1
A major question arises as to the manner in which this bandwidth shall be utilized, namely whether the information should be sent over parallel channels simultaneously, or over a single channel in time sequence. The question is one of feasibility, since ideally the capacity (in the sense of Shannon) of the single channel can be made equal to the total capacity of the parallel channels.*

Advantages are to be gained using either method of transmission. One significant disadvantage of parallel transmission is that the total bandwidth is used less efficiently than for a single channel; filters with rectangular transmission characteristics are not realizable physically, and hence more bandwidth is required (for isolation) than the sum of the individual bandwidths.

* Let \( W \) be the bandwidth, \( P \) the average transmitter power, \( N \) the average noise power, and \( C \) the channel capacity. Then, for a single channel

\[
C = W \log_2 (1 + \frac{P}{N})
\]

For \( n \) parallel channels,

\[
\sum_{i=1}^{n} C_i = \sum_{i=1}^{n} \frac{W}{n} \log_2 \left(1 + \frac{P/n}{N/n}\right) = C.
\]

for an equal distribution of signal power, noise power and bandwidths, in each channel.
A single channel, with no provisions for redundant digits, is suggested for the first version of the system.

If a single audio bandwidth is used, then instructions to individual planes appear in time sequence; the average time between instructions is $15/n$ sec. per plane, or 0.15 sec. if $n = 100$. It becomes necessary, therefore, to provide a memory in the plane, in order that a pilot be capable of carrying out the instructions without giving constant attention to a particular indicator. (A memory might not be necessary for an autopilot).

2°) In order that each plane be able to select the appropriate signal out of the time-shared set of signals, then the equipment in the plane should be capable of identifying the "address" of the instructions, comparing it with the plane's "address" (identification number or designation), accepting the instructions if the addresses coincide, and rejecting them otherwise.

7°) The requirements of a small, light equipment, of low power consumption, which incorporates a small memory (4°), and a digit comparator (2°), can be met by using transistor shift registers; indeed, of present memory devices, transistors seem to fulfill these conditions best.

1°) The most efficient use of Ordevac would involve no stoppage of the machine in obtaining data for the planes. Such a procedure certainly is possible, but does not appear to have a significant advantage of the method proposed here, namely of
shifting the data out of R2 (a shift register) as quickly as possible upon the appearance of a P (print) order in the machine. The costs in time of this latter proposal may be estimated as 
15 \mu s \text{ per shift} \times 25 \text{ shifts} = 325 \mu s + 72 \mu s \text{ for the transfer of the proper order pair} + 11 \mu s = 408 \mu s.

These shifted-out-digits cannot be transmitted directly to the planes, as they appear at a rate of some $6 \times 10^4$ bits/sec.; a shift register is again a convenient memory out of which the stored digits can be shifted at an audio rate. Furthermore, since digital representations are to be used before and after transmission, it seems reasonable to use pulse modulation for transmission. A three-level modulation scheme (1 corresponding to one level, 0 to another, and the absence of modulation to a blank) is simple, and contains a distinctive indication for the beginning or end of a message, namely a blank. Note that this is not the most efficient use of the audio bandwidth, as further coding and decoding operations could decrease the bandwidth necessary to transmit the output information.

3\textsuperscript{i}) and 6\textsuperscript{i}) Analogue indications of the control signal and position are probably more useful to a pilot than digital representations. Digital to analogue converters should then be provided, in the plane, in order to put both the control instruction, and the plane's position, in analogue forms.

5\textsuperscript{i}) A simple device (such as a green light) can give the pilot some indication of whether or not the communication system or plane's equipment is functioning. Error detecting
and correcting techniques can be used to increase the probability of successful operation. Additional checks on malfunction may be furnished by the comparison between the pilot's knowledge of the course he should fly, his reported position, and the course he is asked to fly.

8^) Two way communication is not a necessary feature of the present proposal.

To summarize: The digital representations of the plan position, identification number, and change of heading of every plane is shifted out of Ordvac serially, as quickly as possible, into a shift register. The digits are used to modulate, at an audio rate, a VHF, (or UHF) carrier frequency. These modulated signals are received in every plane, demodulated, and the received identification digits stored and compared with those of the plane. If there is agreement, the plan position digits as well as the change of heading digits are stored and put in analogue form; if there is no agreement, these latter digits are not stored. A simple device indicates to the pilot that he is in communication with the ground, and is receiving control signals.

Two additional remarks concerning the desirability of obtaining the plan position (tied closely to (6)) are of interest. First, it is believed that the output x and y can be compared with input positions, and this comparison used as
an aid in the sorting problem. The details of this suggestion have not been worked out fully, and it is mentioned here only for completeness. The second is that if a multiplicity of radars is used, with VHF transmitters at the radar sites (this is a desirable disposition of the transmitters for reliable communication. See IIB), then the output \( x \) and \( y \) can be used to route the information to the appropriate VHF transmitter.

II. SPECIFIC DESIGN SUGGESTIONS

Multiple radars as well as the routing of information have been included in the block diagram of the overall system (Fig. 1). Error detecting and correcting techniques have not been discussed, as they are not to be incorporated into the initial system. However it should be noted that since the information is transmitted entirely in digital form, the incorporation of these techniques will not materially alter the overall form of the system. The overall system will not be discussed further, as Figure 1 appears to be self-explanatory.

Specific components of the system will now be discussed (see Fig. 2).

A. Two Speed Shift Register

The two speed shift register is intended to serve a dual purpose in the output system. With a high speed shift pulse generator, it will serve to remove information from Ordvac's R2
Fig. 1—Output system
Fig. 2--Two-speed Shift Register
in the minimum time. The 25 digit word can then be stored in the register for at least 25 milliseconds before another message can be prepared by the computer. During this interval the data can be shifted out slowly via a communication link to the proper VHF transmitter at an audio rate. Furthermore, it is again suggested, that a portion of the storage interval may also be used to provide (x, y) information for display, for correlation with the input as an aid in sorting, and to supply positional information on unidentified targets (bogies).

The detailed operation of this circuit is indicated in Figure 2. Initially the register is cleared to 0 in all positions except No. 1. The data ready (DR) flip-flop holds 0. Thus all gates with the exception of No. 5 are closed. The arrival of the P order at the control clears and opens gate No. 1 actuating a fast shift pulse from the 67 kc/sec generator to the register and to Ordvac's R2. After a delay, gate No. 3 is opened, and the first digit read into the register. This procedure is repeated 25 times; when the register holds the 25 digit word initially stored in R2 and the 1 originally cleared into the register has been transferred through gate No. 5 into the DR flip-flop, the control is now automatically returned to Ordvac if the address set with the P order was initially 25. With the arrival of the 1 at the DR flip-flop, gates No. 1, No. 3, and No. 5 are closed, and gates No. 2, No. 4, and No. 6 are opened. Shift pulses from the slow shift
pulse generator are then fed to the register and the shift counter. The data in the register then proceed, digit by digit, through gate No. 6 to the digitalizer. The digitalizer will convert the original two-level signals into a three-level signal. The output of the digitalizer will consist of positive pulses for 1's and negative pulses for 0's. Spaces between digits and between words will have amplitude 0. The output of the digitalizer can be used with any AC coupling scheme in the transmitter modulator and in subsequent equipment. After the 25 digits have been shifted from the register, the shift counter resets itself, the register, and the DR flip-flop, to the initial cleared condition.

B. VHF Transmitter

The VHF transmitter serves as a final relay to the controlled plane. Since it is located at the observing radar, which must be in line-of-sight of the plane, adequate communication to the plane is assured. The information will be relayed to the transmitter station over a communication channel from Ordvac. If a multiplicity of radars is used at the input, the receiver at the VHF transmitter can be equipped with a decoding device to select for relay only those signals with values of x, y within a preassigned range. As this feature will not be required in the first system built, the detailed design of the decoder will not be discussed here.
C. Equipment in Controlled Plane

The equipment in the controlled plane must assure the selection of the proper signal for the proper plane and must provide for use of this information between reports. The detailed operation of those components is indicated in Figure 3.

In the initial state the 7-digit decoding register is cleared to 0 in all positions except No. 1. The Data Ready (DR) flip-flop holds 0. Then gates No. 1 and No. 4 are open and gates No. 2 and No. 3 closed. The incoming signal is detected by the VHF receiver. The three level signal initially set by the digitalizer at the two-speed shift register is applied to the shift pulse generator and to the decoding register. The process of shifting digits continues until the first seven digits are read into the decoding register.

The 1 initially cleared into position 1 arrives at the DR flip-flop. After a delay of 150μsec. (to assure the arrival of the 7th digit in the decoding register), gates No. 1 and No. 4 are closed and a delayed clear pulse started. The "and" circuit No. 1, preset to the code of the plane, is enabled. If a coincidence is not recognized, the next 18 digits of the received message are blocked by gates No. 1 and No. 2, and the circuit is returned to the initial state by the delayed clear pulse, after the message is completed.

In the event that a coincidence is observed by "and" circuit No. 1, gates No. 2 and No. 2 are opened for a sufficient
Fig. 3—Equipment in Controlled Plane
time to permit storage of the 18 positional and control digits in the 18 digit shift register and to re-set the control light clock. Conversion of the data to analogue form is effected from the 18 digit shift register. These data are available until the next properly coded signal is received. If a new signal is not received within 20 seconds, a red "Control light" will be turned on indicating to the pilot that he is no longer under control. The most recent data are still available in the 18 digit register if needed.

The conversion of change of heading data to analogue form can be effected by using a set of weighted constant current generators, an analogue adder, and a centered zero ammeter for indication. A variety of means exist for obtaining $x$ and $y$ in analogue form for presentation to the pilot. It is not yet known which, if any, scheme will be used at first.

Finally, the pilot can turn off a green light (indicating the presence of new data) when he has executed a control signal, turning on a yellow light, which will indicate the execution of the control signal.