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TELEGRAPH TERMINAL SET (AN/FGC-14)

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ABSTRACT

The AN/FGC-14, developed at NRL, is an electronic device which, when used with a suitable cipher generator, permits instantaneous on-line enciphering and deciphering of teletype signals. It was primarily designed for use at large communication centers in conjunction with the standard single-sideband equipment (SSB) although it is not limited to such use. Automatic protection devices included in the equipment maintain a continuous check on the adequacy and accuracy of the enciphering process. The traffic handling capability of the SSB equipment is increased from 360 words per minute to 468 words per minute through the use of the AN/FGC-14.

PROBLEM STATUS

This is a final report on one phase of this problem. Work on other phases is continuing.

AUTHORIZATION

NRL Problem 39R01-11
RDB Projects: NE 020-923,
NE 021-402, and NE 021-409

Manuscript submitted June 10, 1952

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TELEGRAPH TERMINAL SET (AN/FGC-14)

INTRODUCTION

In the spring of 1951, after several months of extensive field tests on the UXC-2* fascimile security equipment, it was believed highly desirable that a similar system be developed for other types of terminal equipment. In particular, it was thought that the AFSAX-500**, a synchronous cipher generator originally developed at the Naval Research Laboratory for use with the UXC-2, could be used directly for the enciphering of telegraph signals.

The need for a new system of encrypting information is made clear by a review of the method now in use. At present the process is slow and tedious, requiring large numbers of trained operating personnel. Each message is sent to the code room where it is enciphered. Before it can be transmitted, however, the encrypted message must be deciphered as a check on its accuracy. After reaching its destination the message must again be sent to the code room for deciphering. This time-consuming process places a definite limit on the amount of classified traffic which can be handled. A great percentage of traffic, therefore, is sent in the clear. The headings of even the enciphered messages are transmitted in plain text. Hence, traffic analysis is a relatively easy matter.

The AN/FGC-14 equipment, together with the ASFAX-500 key generator, is an electronic cryptographic system for use with teletype signals which permits instantaneous on-line enciphering and deciphering of information. It maintains a continuous check on the accuracy of the encrypted information. This system also makes possible the simultaneous transmission of eight channels of enciphered teletype over six normal channels. It was primarily designed for use at large communication centers in conjunction with the single-sideband system, although it does not necessarily have to be confined to this system. It was designed to operate continuously, handling all traffic regardless of classification. This equipment produces a continuous signal that gives no indication of the number of messages sent, their headings or lengths, or the classification assigned to the content of these messages; hence, traffic analysis is extremely difficult. When finally adopted, the AN/FGC-14 will greatly reduce, if not eliminate, the lag in traffic handling in times of high peak loads. Also a large saving in personnel required for enciphering and deciphering messages will be realized.

A working model of the AN/FGC-14 was constructed at the Naval Research Laboratory. The unit was installed in the Naval Communication Radio Photo Terminal at the Navy Department, and the radio facilities of that activity and of Radio Central were used for the preliminary tests.

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* CNO Publication, "Telegraph Multiplex Set Instruction Manual (AN/UXC-2)"

** CSP 5501

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DESCRIPTION OF THE SYSTEM EMPLOYING THE AN/FGC-14

A block diagram of the system employing the AN/FGC-14 is shown in Figure 1. Information in the form of perforated tapes is fed into the teletype transmitter distributors. The output of the eight distributors, which are start-synchronized with the system, is coupled into the AN/FGC-14, where it is multiplexed into six channels and combined with the cipher output of the AFSAX-500 key generator. A second key generator is used as a continuous independent check on the signal output of each channel. Provision is made in the equipment to disable the channel or channels that show a predetermined percentage of errors. The key generators are synchronized with the system by means of a common frequency standard. The output is fed into the "U.P." equipment, a two-tone single-sideband terminal system. The U.P. provides six telegraph circuits over one radio or wire circuit. Each telegraph circuit employes two pairs of tones for frequency diversity transmission. The lower frequency of each pair corresponds to mark, the upper frequency (170 cycles higher) to space. The U.P. output is used to modulate a single-sideband transmitter, or to feed a land-line circuit. If the distances are no greater than that used by standard teletype machines, it is also possible to transmit directly into six land lines from the AN/FGC-14.

At the receive terminal, the signal from the single-sideband receiver, or from the land line, is coupled to the receive U.P. The U.P. is operated as in a normal telegraph circuit. The signal, a mixture of 24 tones, is passed through filters which separate the tones into six channels. From these tones, the mark-space signals are reconstructed. The six-channel output of the U.P. is coupled to the receive portion of the AN/FGC-14, where it is deciphered by combining with the output of the receive AFSAX-500. Here, also, it is demultiplexed to reproduce the eight channels of information. Eight teleprinters are driven in a normal manner by the output of the AN/FGC-14.

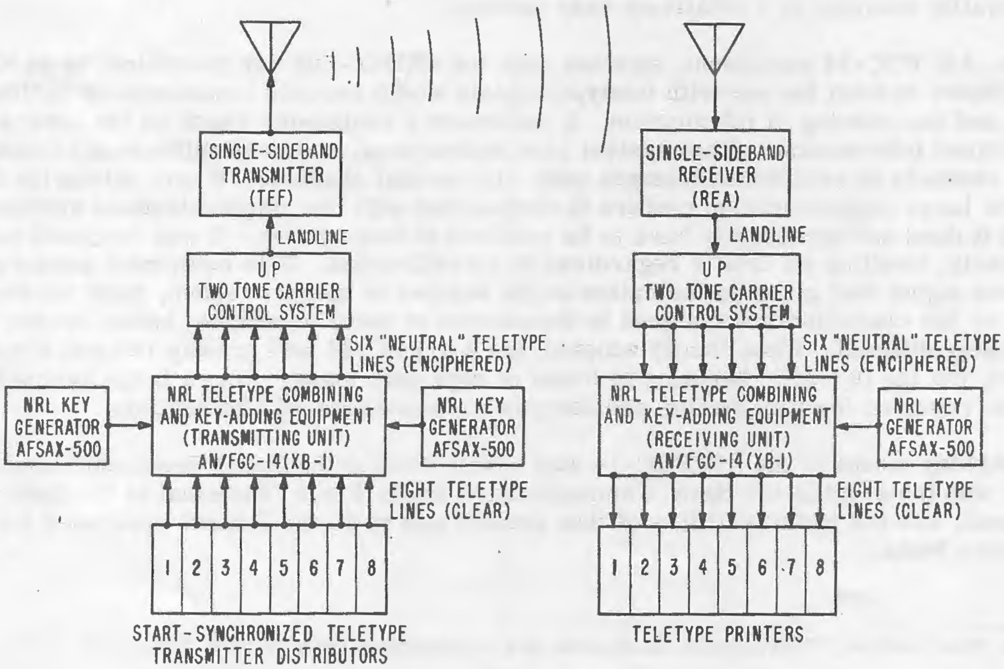

Figure 1 - System employing AN/FGC-14 – block diagram

SYNCHRONIZATION AND TIMING OF THE SYSTEM

The basic problem of employing the synchronous AFSAX-500 key generators to encrypt telegraph signals was simplified by designing the equipment around a synchronous system. The success of the UXC-2 indicated that such a system was entirely practical. The teletype character is composed of two operating elements (the start and stop elements) and five intelligence elements. In a synchronous system it becomes feasible to encrypt not only the intelligence elements, but also the operating elements, a necessary requisite for obtaining a high degree of security.

Synchronism between the equipment at the transmit and at the receive terminals is maintained through the use of stable frequency standards. Initial synchronism is obtained by an operational procedure to be discussed later. The transmit and receive portion of the AN/FGC-14 each have their own timing unit, the stability of which is derived from the frequency standard. The timing units serve to maintain the proper time relationships among the transmitter distributors, the key generators, and the various circuits in the AN/FGC-14.

In the standard 60-word-per-minute teletype code, the start and five intelligence elements are each 22 milliseconds in duration. The stop element is 31 milliseconds long. For security reasons, as well as to facilitate the enciphering process, there must be no differentiation between the lengths of the various signal elements. The stop element is not transmitted, since, in a synchronous system, it can easily be regenerated in the receiver unit. This leaves 31 milliseconds during which time no intelligence is transmitted. By decreasing slightly the length of the teletype signal element (from 22 to 20.8 milliseconds) eight equal-length elements are obtained in a slightly greater time than that required for the transmission of a single character of normal teletype. Since only six signal elements per character are transmitted, two elements (41.6 milliseconds) contain no intelligence. This time is used to advantage by employing a simple time-division multiplexing system, making it possible to utilize the 41.6 milliseconds of time from each of three of the SSB channels for another channel of teletype.

The net result is that for each three single-sideband channels, an extra channel has been gained. Hence, eight channels of the enciphered teletype information can be transmitted on the standard six-channel SSB equipment, and the traffic handling capabilities can thus be increased from 360 words per minute to 468 words per minute.

A timing chart illustrating the time relationships involved in the operation of the first three channels of the AN/FGC-14 transmitter unit is shown in Figure 2. The last three channels operate similarly.

In order to eliminate the necessity for storing information, the output signal from the teletype transmitting distributors must occur in synchronism with the operation of the associated circuitry in the AN/FGC-14. This is done by tripping the release magnet of the TD in synchronism with the transmitter timing unit, and mechanically stopping the commutator brushes after each revolution. It is also necessary to decrease the TD signal element length from 22 milliseconds to about 20.8 milliseconds. This is accomplished in a series-governed motor by increasing its speed, or, if the motor is of the synchronous type, by changing the gear ratio.

The transmitter distributors must be tripped in the proper sequence in order to accomplish the multiplexing of the information from four TDs into the three channels. TD 1 is tripped so that the commutator brushes reach the start segment at a certain time. TD 4 is tripped to allow its start element to begin six elements (124.8 milliseconds) later. The input

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to Channel A of the AN/FGC-14 is gated to admit first the start and five intelligence elements of TD 1 and then the start and first intelligence element of TD 4. TD 2 is released two elements after TD 1. The input to Channel B is gated to admit the six elements from TD 2 followed by intelligence elements two and three of TD 4. In a like manner, TD 3 is released four elements after TD 1, allowing the last two elements of TD 4 to be gated into Channel C following the signal from TD 3.

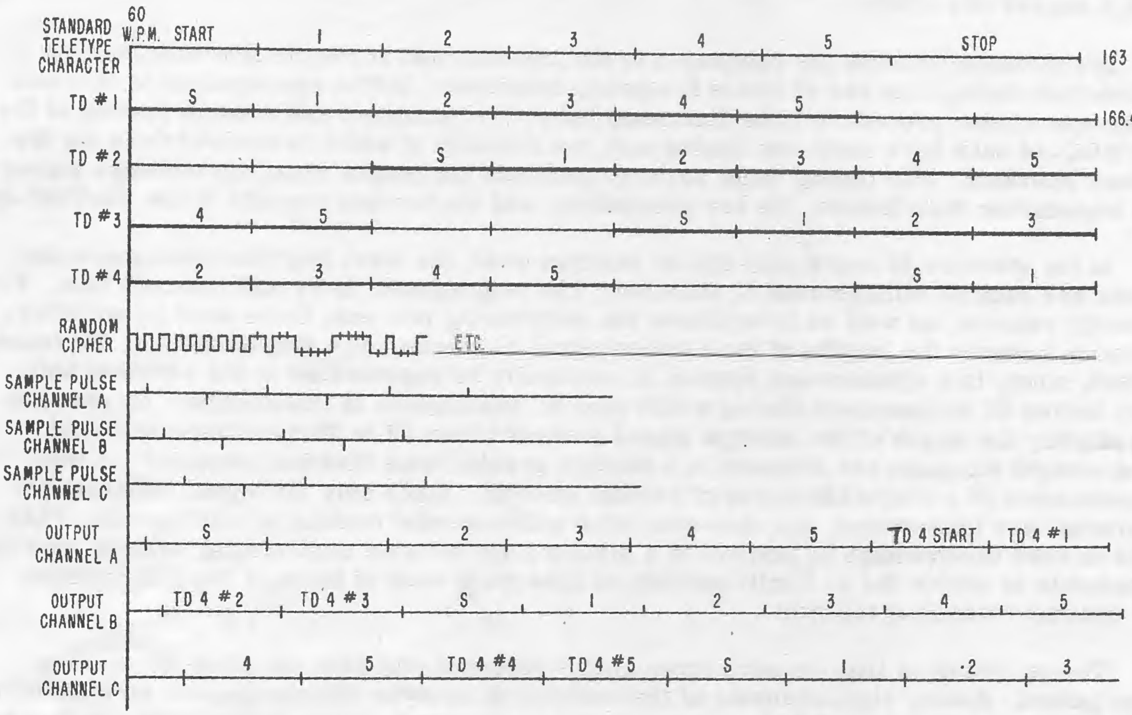

Figure 2 - Synchronization and timing chart

The signals from the transmitter distributors are then combined with the cipher output of the AFSAX-500 key generators. A key generator is a synchronous device delivering a mark-space signal. The length of its output cipher elements is determined by its driving frequency which, in this case, is 769.23 cycles per second obtained by frequency division of the 100-kc standard frequency. Each cipher element, therefore, is 1.3 milliseconds in duration, or 1/16th of the length of the teletype signal element. It is necessary in the interest of security that a particular cipher element be used to encrypt only one teletype signal element of one channel only. Therefore, the sampling pulses which sample the cipher and signal elements in the combining and checking circuits must occur at different times in the different channels. With a time difference of 2.6 millisecond between the sampling pulses of the successive channels, Channel B uses the second element of cipher after Channel A, Channel C uses the second element of cipher after Channel B, and so forth. Hence, each channel is enciphered with a different cipher signal. The output from each channel is a mark-space signal with a basic element length of 20.8 milliseconds.

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The time relationships involved in the operation of the receive portion of the AN/FGC-14 are similar to those in the transmit section. The receive key generator is driven at the same speed, 769.23 cycles per second, giving a basic element length of 1/16th of the length of the received signal elements. By the same method employed in the transmit portion, the proper cipher element is chosen to decipher each channel. The output from each channel is directed sequentially to its two teleprinters (for example, Channel A to teleprinters 1 and 4) by gating circuits which are driven from the receiver timing unit.

The transmit and receive terminals must be synchronized each time the AN/FGC-14 is placed in operation. The transmit terminal initiates a pulse which results in the simultaneous starting of the transmit and receive key generators. An oscilloscope, synchronized from the receive timing unit, is used to monitor the receiver output to teleprinter 1. A continuous marking signal is transmitted from TD 1. The receive key generator is phased into exact synchronism with the transmit key generators. A stationary step waveform on the oscilloscope indicates synchronism. The receive timing unit is then phased with the transmit timing unit; synchronism being indicated by a definite position of the step waveform on the face of the oscilloscope.

DESCRIPTION OF THE AN/FGC-14

Pictures of the experimental AN/FGC-14 and associated key generators are shown in Figures 3, 4, and 5. A block diagram of the AN/FGC-14 is shown in Figure 6. A secondary 100-kc frequency standard is used as a stable frequency source for maintaining synchronism between the equipment at the transmit and receive terminals. The output is divided to 769.23 cps by means of a heterodyne frequency divider.

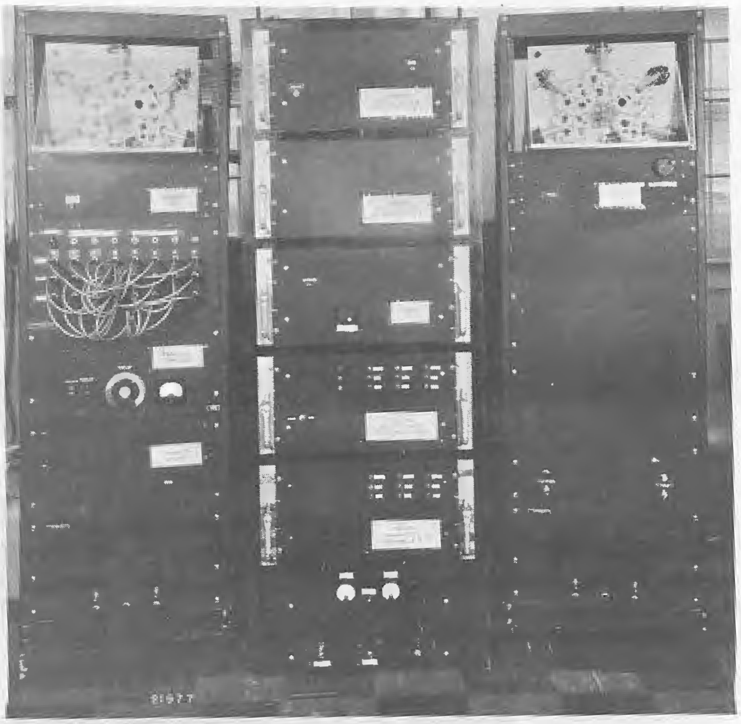

Figure 3 - Experimental AN/FGC-14 and key generators. Front view.

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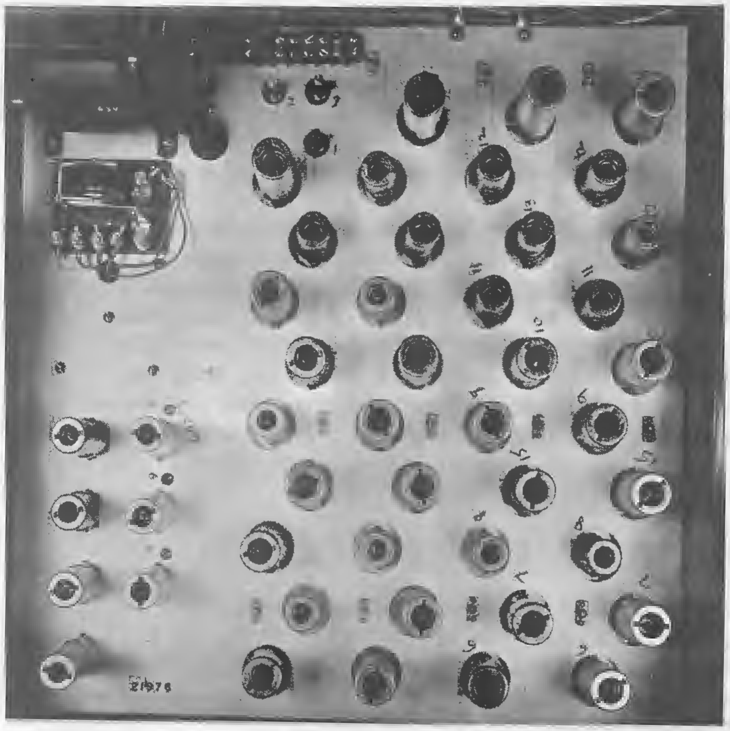

Figure 4 - AN/FGC-14 transmit chassis. Top view.

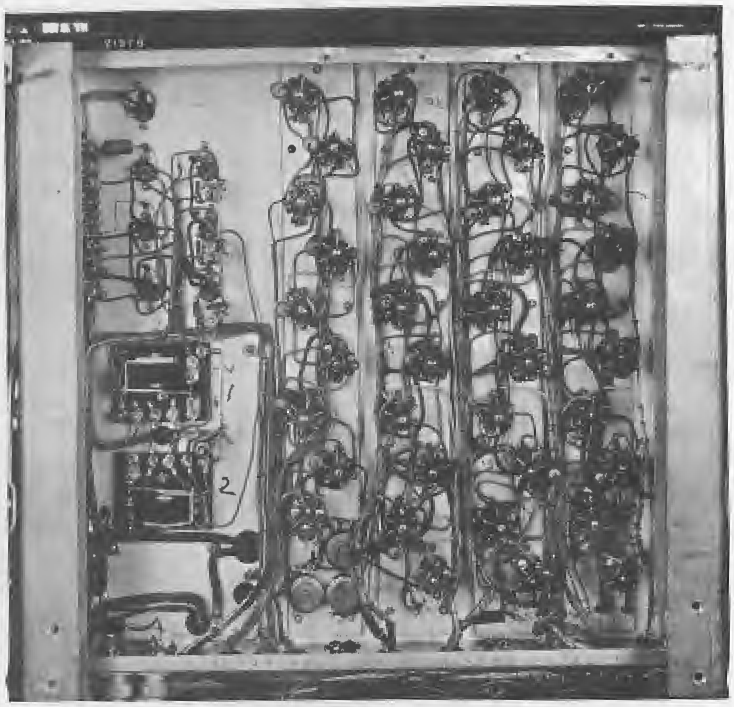

Figure 5 - AN/FGC-14 transmit chassis. Bottom view.

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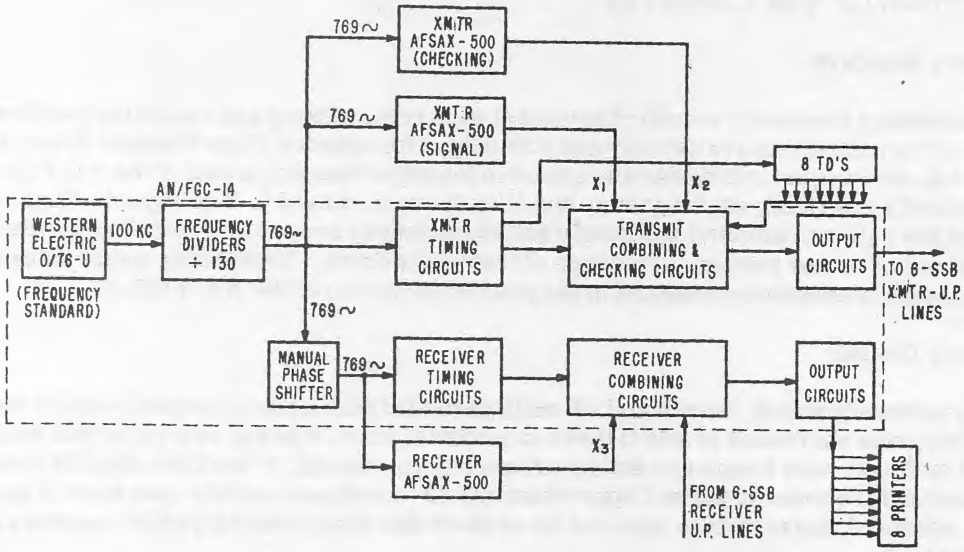

Figure 6 - AN/FGC-14 – block diagram

Transmit Circuits

The 769.23-cps output of the frequency divider is used to drive the two transmit AFSAX-500 key generators. The checking key generator has a continuous phase shifter in its input circuit permitting its cipher output to be phased with that of the first key generator. The output of the frequency divider also is used to drive the transmit timing circuits. The timing circuits furnish sampling pulses and gating square waves to the transmit combining and checking circuits. They also furnish pulses to activate the teletype transmitter-distributor (TD) trip circuits.

The transmit combining and checking circuits are comprised of six identical channels. Here the signals from the eight TD are multiplexed and added to the cipher from the transmit AFSAX-500. Each of the six combining circuits is paralleled by a circuit which combines the same TD information with cipher from a second key generator. The two resulting signals are then compared with each other. Any discrepancies automatically cause the particular channel in difficulty to be disabled. Each of the six outputs from the transmit equipment deliver a 60 ma mark-space type signal for feeding the U.P. or the land lines.

Receive Circuits

The frequency divider output is coupled to the receive timing circuits through a manual phase shifter permitting the receive circuits to be properly phased with the received signals. The receive timing circuits furnish sample pulses and gating square waves for the proper operation of the receive combining circuits. A second phase shifter is used in the drive circuit of the receive AFSAX-500 to permit the phasing of the receive key generator with the transmit key generator. In the same manner as in the transmit circuits, the signals from the U.P. are combined with the output of the receive key generator and deciphered. The signals are then demultiplexed and the eight outputs are used to drive the eight teleprinters.

DESCRIPTION OF THE CIRCUITRY

Frequency Standard

A secondary frequency standard is used at each transmitting and receiving terminal. Because of its immediate availability and stability, a forerunner of the Western Electric 0/76-U 100-kc Frequency Standard was used in the experimental model of the AN/FGC-14. The standard has an inherent frequency stability of one part in 10^8. It is expected that the Navy will adopt the policy of employing a single stable frequency source to drive all equipment at each communication center requiring this type of frequency drive. This policy would make unnecessary the inclusion of a frequency standard in the production model of the AN/FGC-14.

Frequency Divider

As previously stated, the normal 22-millisecond signal element output from the transmitter distributors was shortened to fulfill three conditions: first, it has to be a value that could be obtained by fairly easy frequency division from 100 kc; second, it has to be slightly less than 22 milliseconds in order to permit approximately 60-word-per-minute operation of each telegraph circuit; and third, the elements must not be so short that they cannot directly operate a standard teleprinter.

The heterodyne principle of frequency division was used in order to obtain a stable output. The input to the frequency divider is 100 kc. A division of 130 (accomplished in two stages) produces an output frequency of 769.23 cps which is used to drive the key generators as well as the transmit and receive timing circuits.

As shown in Figure 7, the first heterodyne divider reduces 100 kc to 7.69 kc. The 100-kc signal is fed into the grid of V1, a pentagrid converter. The plate circuit of V1 is sharply tuned to 7.69 kc so that it can have no other appreciable output. The output of V1 is fed into V2a which quadruples to 30.77 kc. This frequency is coupled to V2b where it is tripled to 92.31 kc, which in turn drives grid 3 of the pentagrid converter, thus heterodyning with the 100 kc, to produce the 7.69-kc stable output for the portion of the divider. The second portion of the divider converts the 7.69 kc to 769 cps in the same manner as the first except that V4a and V4b are both frequency triplers. The circuit is able to start in operation because of its unstable character when there is no input signal.

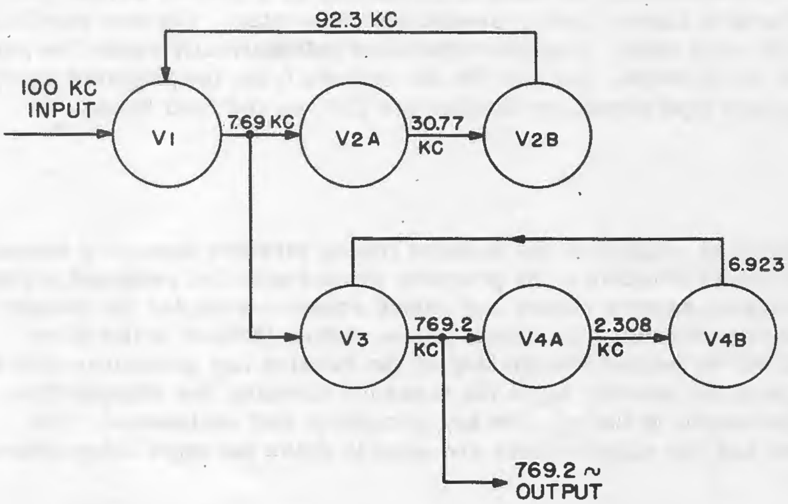

Figure 7 - Frequency divider - block diagram

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Timing Unit Ring Commutators

The ring commutators of the receiving and transmitting timing units are alike in circuit detail. The 769.23-cps input from the frequency divider is passed through a squaring amplifier and divided to 384.61 cps by means of an Eccles-Jordan trigger circuit. The differentiated output is used to drive the first ring-commutators.

The basic circuit in the ring commutators is a bistable circuit using twin triode tubes. A block diagram is shown in Figure 8. The output appearing at each of the eight anodes of tubes V1204, V1205, V1206, and V1207 is a square wave. The time duration of each cycle is 20.8 milliseconds. As illustrated, the square wave appearing at output #2 is displaced in time 2.6 milliseconds from that appearing at output #1. Square wave #3 is displaced 2.6 milliseconds from square wave #2, and so forth. This sequence is initiated and maintained by the use of correcting pulses (dashed lines in the figure) which are coupled from the anode of one stage to the control grid of another. Each square-wave output of the first ring commutator is differentiated to produce pulses having a repetition rate of 48.08 per second, or 1/8th of the input frequency. Six of the eight outputs from the first ring-commutators of both transmit and receive timing units are used for sampling the signals in the six channels. In the transmitting unit the pulses are also used in the transmitter distributor trip circuits.

The second ring-commutator in both the transmit and receive units is driven from the first. The eight outputs are square waves of 166.4 milliseconds duration (6.01 cps) with successive outputs displaced 20.8 milliseconds in time. These square waves are used in the gating circuits in both the receive and transmit units. In the transmit unit they are also used in conjunction with the pulses from the first ring commutator to provide for tripping of the transmitter distributors.

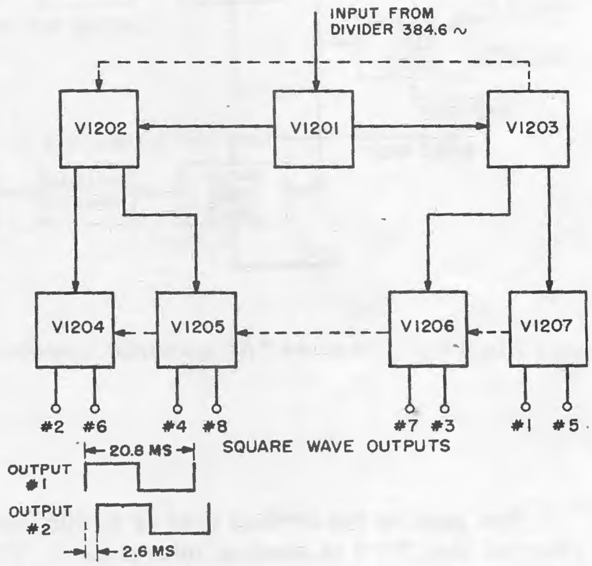

Figure 8 - Ring commutator-block diagram

Transmit Combining and Checking Circuits

The transmit combining and checking circuits for each of the six channels are identical in circuitry. The operation of Channel A will be described. A block diagram of transmit Channel A is shown in Figure 9; a schematic diagram in Figure 10. The multiplexing circuit is actually a part of both the signal and checking binary adding circuit (Figure 11).

The multiplexing and binary adding circuit has several inputs:

(1) Two-level information, zero or negative 105 volts, from transmitter distributors 1 and 4, is applied to the suppressor grids of V2002 and V2003.

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(2) Two-level cipher, X_1, zero or negative 50 volts, from the transmit AFSAX-500, is applied to the suppressor grid of V2004.

(3) Gating voltages from the transmit timing circuits, negative 10 or negative 50 volts, are applied to the control grid of V2002 and V2003 for the multiplexing of signals from TD 1 and TD 4.

(4) Sampling pulses from the transmit timing circuit are applied to the control grids of V2002, V2003, and V2004, superimposed upon the gating voltages described in (3).

The output of this circuit consists of positive and negative pulses, the polarity being determined by the combination of X_1 with the TD signal information.

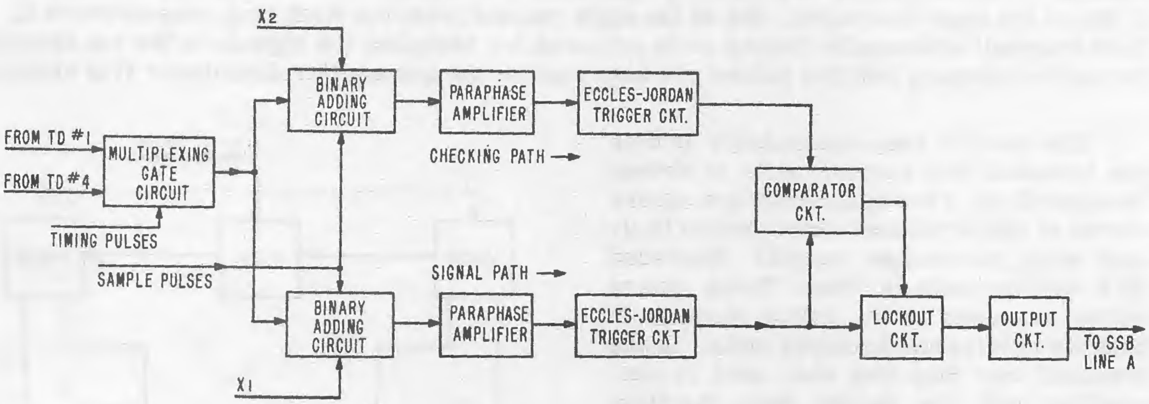

Figure 9 - Channel "A" transmit combining and checking circuits – block diagram

The gate on the control grid of V2002 conditions it to conduct for the 124.8-millisecond interval that TD 1 is sending information. V2003 is conditioned by a gate on its grid during the remaining 41.6 milliseconds when TD 4 is sending its first two elements. The control grid of V2004 is biased at a negative 10 volts. The positive portion of the sampling pulses permit V2002, V2003, and V2004 to conduct through their screen grids. When the signal from the TD on the suppressor grid of the conditioned tube (V2002 or V2003) is zero volts, the plate of the tube conducts, and negative pulses are produced in the plate circuit by the positive pulses on the control grid. When the signal is negative, the plate is cut off and there is no output from that tube's plate circuit. V2004 operates in a like manner with cipher X_1 impressed on its suppressor grid. The tubes V2002, V2003, V2004, and V2006a have a common 24-ohm cathode resistor; thus, V2002, V2003, and V2004 drive the cathode of V2006a with very small positive pulses. The plate output of V2006a consists of a positive pulse for each positive sampling pulse.

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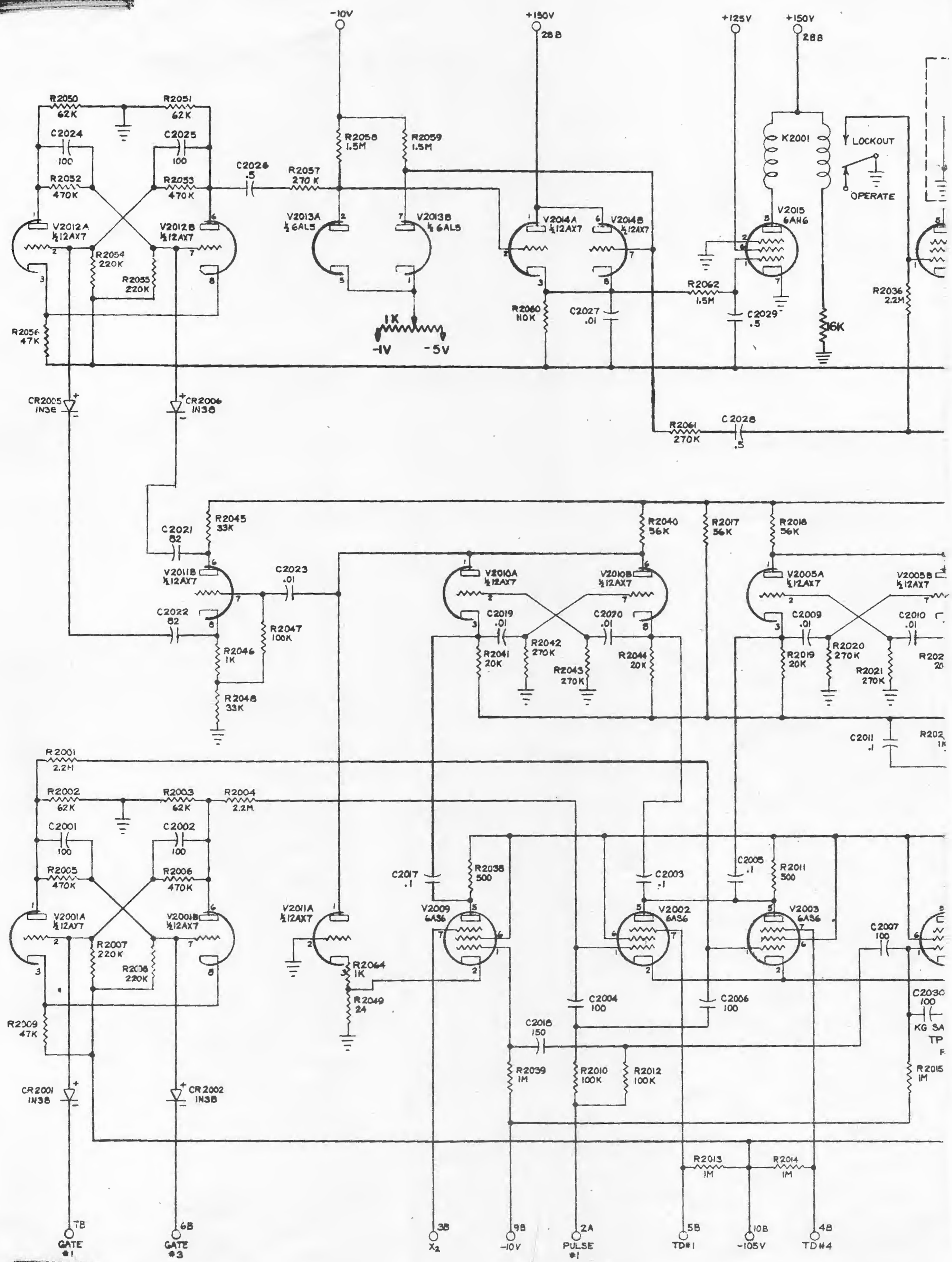

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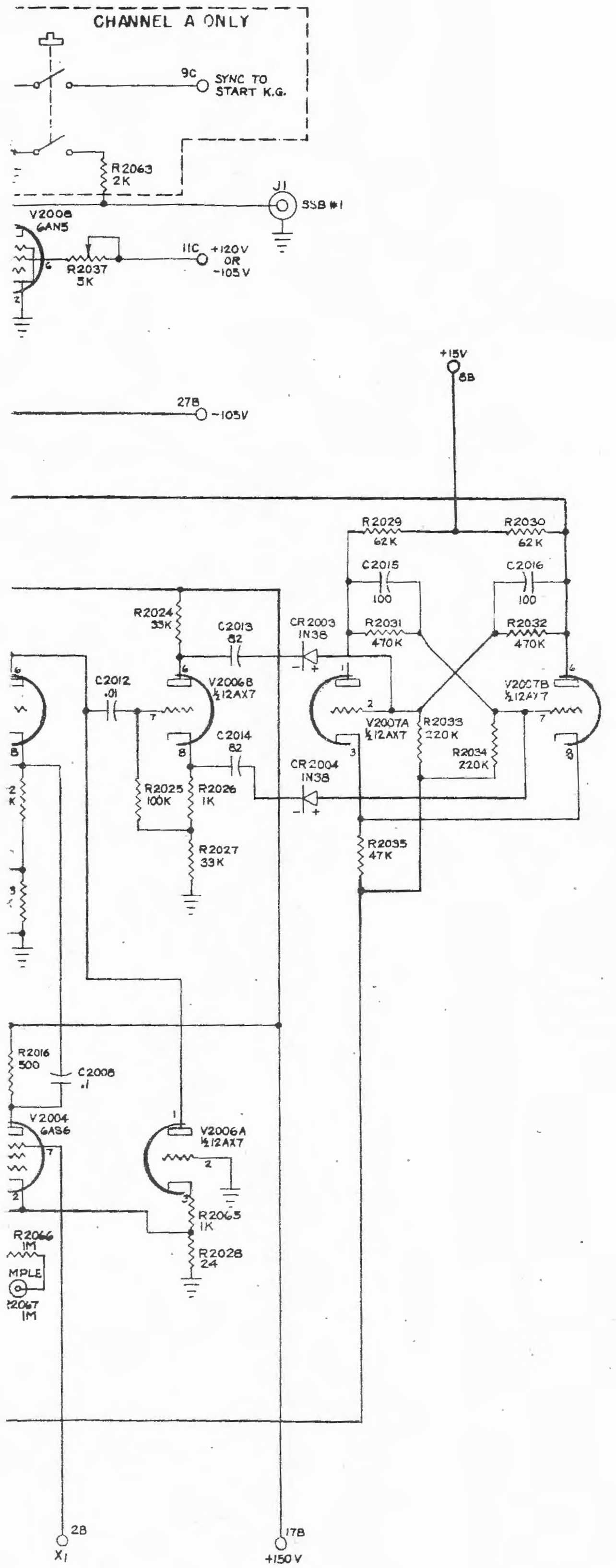
Figure 10 - Transmit Channel "A" - schematic diagra


CHANNEL A ONLY
9C
SYNC TO START K.G.
R2063 2K
J1
SSB #1
V2008 6AN5
R2037 5K
11C
+120V OR -105V
27B
-105V
+15V
8B
R2029 62K
R2030 62K
C2015 100
C2016 100
R2031 470K
R2032 470K
R2024 33K
C2013 82
CR2003 1N38
C2012 .01
V2006B ½12AX7
V2007A ½12AX7
V2007B ½12AX7
R2033 220K
R2034 220K
C2014 82
CR2004 1N38
R2025 100K
R2026 1K
R2027 33K
R2035 47K
R2016 500
C2008 .1
V2004 6AS6
V2006A ½12AX7
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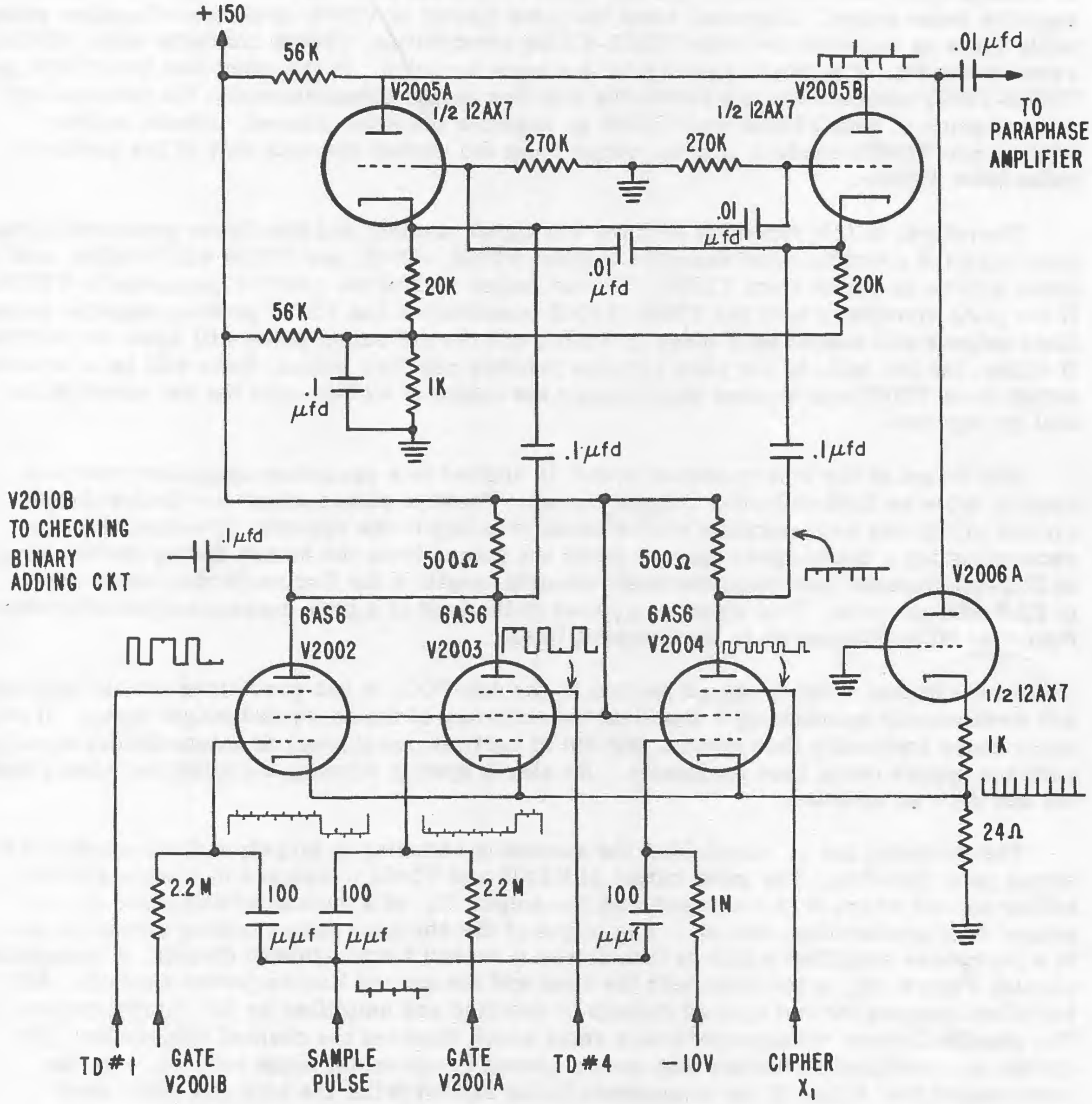

Figure 11 - Transmit binary adding circuit - schematic diagram

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The tubes V2005a and V2005b are biased just beyond cut-off by the voltage divider in the cathode circuits. The common output of V2002 and V2003 is impressed on the cathode of V2005a and also on the control grid of V2005b. Similarly, the output of V2004 is coupled to the cathode of V2005b and to the control grid of V2005a. When a negative pulse is received from the V2002-V2003 combination but not from V2004, V2005a will conduct while V2005b is only driven further beyond cut-off. The negative pulse from the plate of V2005a more than cancels the positive pulse from the plate of V2006a, giving a resultant negative pulse output. Likewise, when the plate circuit of V2004 furnishes a negative pulse while there is no output from the V2002-V2003 combination, V2005b conducts while V2005a remains cut off. The final output again is a negative pulse. In the event that both V2004 and V2002-V2003 combination are delivering negative pulses simultaneously, the cathodes and control grids of both V2005a and V2005b go negative the same amount. Hence, neither V2005a nor V2005b conduct, and the output from the circuit consists only of the positive pulse from V2006a.

Therefore, in this circuit if both the TD signal element and the cipher generator element have negative potential when sampled, neither V2002, V2003, nor V2004 will conduct, and there will be no output from V2005. The net output will be the positive pulse due to V2006a. If the plate circuits of both the V2002-V2003 combination and V2004 produce negative pulses, their outputs will cancel each other in V2005, and the net output pulse will again be positive. If either, but not both, of the plate circuits produce negative pulses, there will be a negative output from V2005 which more than cancels the output of V2006a, and the net output pulse will be negative.

The output of the binary adding circuit is applied to a paraphase amplifier which is used to drive an Eccles-Jordan trigger circuit. Positive pulses cause the Eccles-Jordan circuit to flip one way; negative pulses cause it to flip in the opposite direction, thereby reconstructing a mark-space signal. Since the pulses from the binary adding circuit occur at 20.8-millisecond intervals, the basic element length of the Eccles-Jordan output signal is 20.8 milliseconds. This signal is applied to the grid of a high-current-output tube which furnishes 60 milliamperes to the transmit lines.

Each channel of the transmit portion of the AN/FGC-14 has provisions for automatically and continuously maintaining a check on the accuracy of the encrypted output signal. If errors occur more frequently than about 1 percent of the time, the channel is automatically disabled until the errors occur less frequently. An alarm system informs the operator when a channel has been so disabled.

The circuitry for accomplishing the automatic checking is largely a duplication of the signal path circuitry. The pulse output of V2002 and V2003 is coupled to a second binary adding circuit where it is combined with the output, X_2 of a second AFSAX-500. X_2 is phased into synchronism with X_1. The output of the checking binary adding circuit is fed to a paraphase amplifier which in turn drives a second Eccles-Jordan circuit. A comparator circuit, Figure 12, is fed from both the first and the second Eccles-Jordan circuits. Any variation between the two applied signals is detected and amplified by the comparator circuit. The resultant error voltage operates a relay which disables the channel output tube. The circuit was designed to include only active circuit components, made necessary by the requirement that if any of the components in the circuit fails, the lock-out relay must operate.

The singals from the two Eccles-Jordan circuits are coupled through capacitors to opposite grids of the comparator tube, V2014, and a dc level of about negative 15 volts is injected on the grids. In order to minimize the effect of any difference in amplitude between

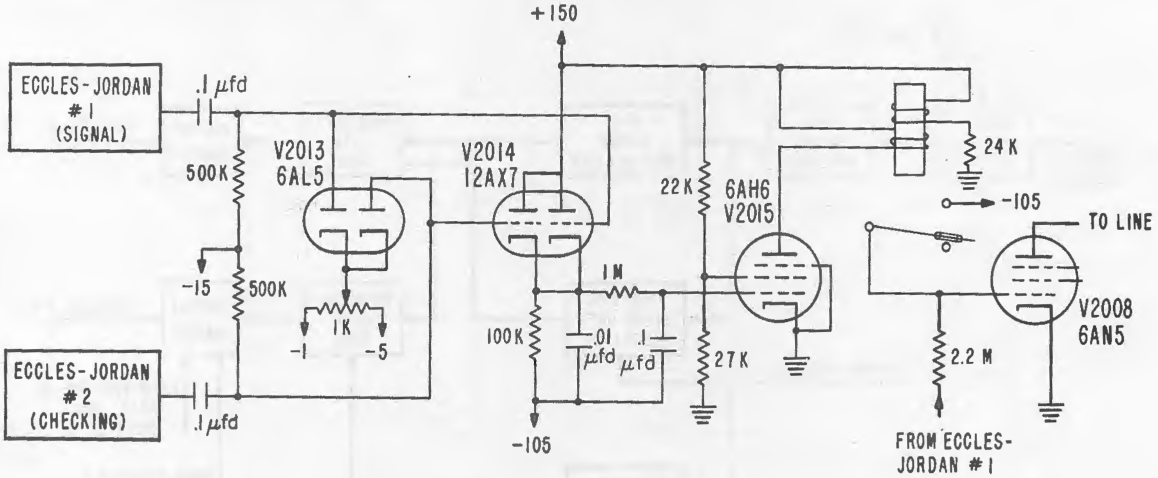

Figure 12 - Comparator and lock-out circuit – schematic diagram

the two input signals, and to keep the grids from going positive, a clipper tube, V2013, also is inserted in the grid circuits. V2014 is operated in push-pull, so that with errorless signals one half of the tube is conducting at all times. Under normal conditions the cathode voltage of V2014 is slightly negative, the degree depending upon the level to which the cathode of V2013 is set. An error from one of the Eccles-Jordan circuits produces, on the cathode of V2014, a negative square wave, which is filtered and applied to the grid of V2015 causing its plate current to decrease. The relay in the plate circuit of V2015 has a double winding, one of which draws a constant current of approximately six milliamperes. The current through the other winding, which flows in the opposite direction, is controlled by the grid voltage of V2015 and is set at six milliamperes by the adjustment of the clipping level of V2013. With errorless operation, therefore, the relay remains de-energized because of cancellation of the flux in the relay core. When errors occur with sufficient frequency, the current through the tube decreases and the relay operates, applying a negative voltage to the grid of the output tube V2008. If, at any subsequent time, the signal again becomes errorless, the relay automatically opens and normal operation is resumed.

Receive Combining Circuits

The receiver circuits consist of six similar channels. Only receiver, Channel A, will be described. A block diagram of Channel A is shown in Figure 13, a schematic diagram in Figure 14. The received signal from the SSB lines is combined with the cipher from the received AFSAX-500 key generator in the binary adding circuit. From the first ring commutator, located in the receive timing unit, the proper sampling pulses are provided for each channel. The binary adding circuit is similar to that used in the transmit section, except that no provision is made here for multiplexing the channel information since this is done in a later stage.

As shown in Figure 15, the output of the binary adding circuit, consisting of positive and negative pulses, is fed into a paraphase amplifier, which in turn is used to drive the signal regenerator—an Eccles-Jordan trigger circuit. The regenerated signal intelligence is applied simultaneously to the suppressor grid of teleprinter #1 gate tube, V4002, and also to the corresponding grid of teleprinter #4 gate tube, V4004. By properly gating V4002 and V4004, six elements of the input signal are applied to teleprinter #1 and the remaining two are applied to teleprinter #4.

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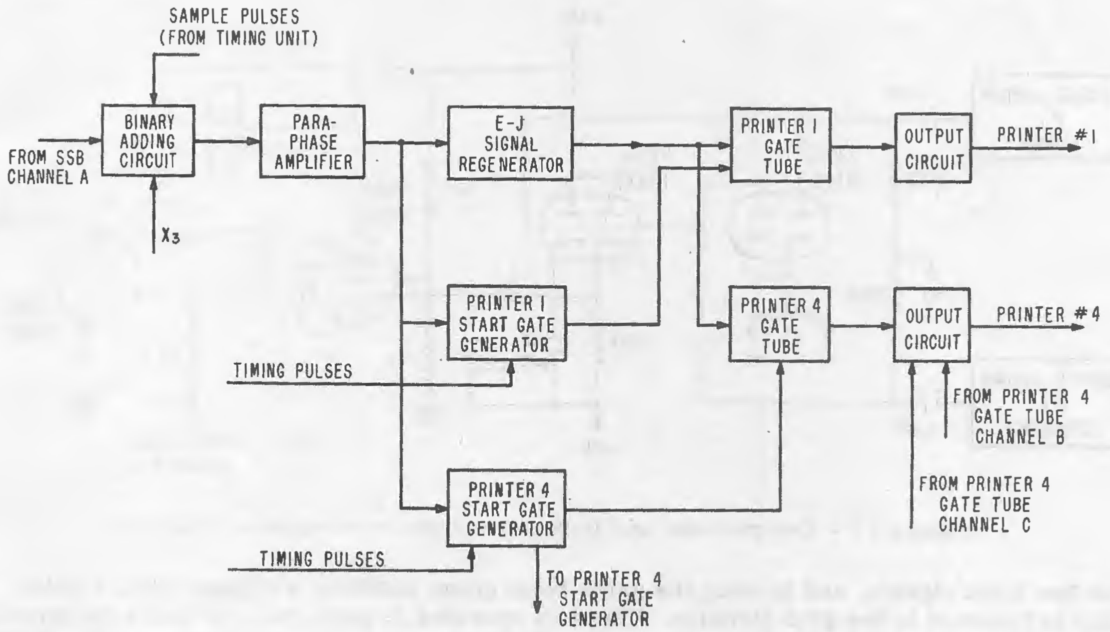

Figure 13 - Channel "A" receive combining circuits - block diagram

A gating voltage with a 20.8 millisecond period is applied to the suppressor grid of V4009 during the time a start pulse would be received. This voltage is derived from the second ring-commutator by the addition of the proper 166.4-millisecond output square waves. If a pulse from the paraphase amplifier occurs during the time the tube is gated for conduction, a pulse will appear on its plate. This will trip trigger circuit "M." Tube V4002 is, therefore, in position to transfer the start and five intelligence elements of the signal from the signal regenerator to teleprinter #1 output tube. Six elements (124.8 milliseconds) later, V4011, now being properly gated with a 20.8 millisecond square wave, will automatically trigger the circuit back thereby regenerating a stop element of 41.6 milliseconds duration and stopping the operation of teleprinter #1 for that character.

If, during the interval that V4009 is gated for conduction, no start pulse appears on its grid, trigger circuit M will not "flip." The next five signal elements will not be transferred to the teleprinter to throw the teleprinter out of synchronism. Hence, an inadequate signal received during this interval will result in the omission of only a single character. This method of gating also reduces the possibility of a false start signal (due to atmospheric bursts) being impressed on the teleprinter.

The gate generator for teleprinter #4 functions in the same manner as does teleprinter #1 gate generator. However, the inputs to teleprinter #4 gate generator are so arranged that V4004 is conditioned to conduct only during the 41.6 millisecond interval that V4002 is not conditioned. Tube V4004 is cut off for the remaining 124.8 milliseconds. As in the #1 gate generator, the circuit functions only if a start pulse is applied to the control grid of V4012 while a positive gate is applied to the suppressor grid. A pulse applied to the control grid of V4014 automatically triggers the circuit back after the 41.6 millisecond interval.

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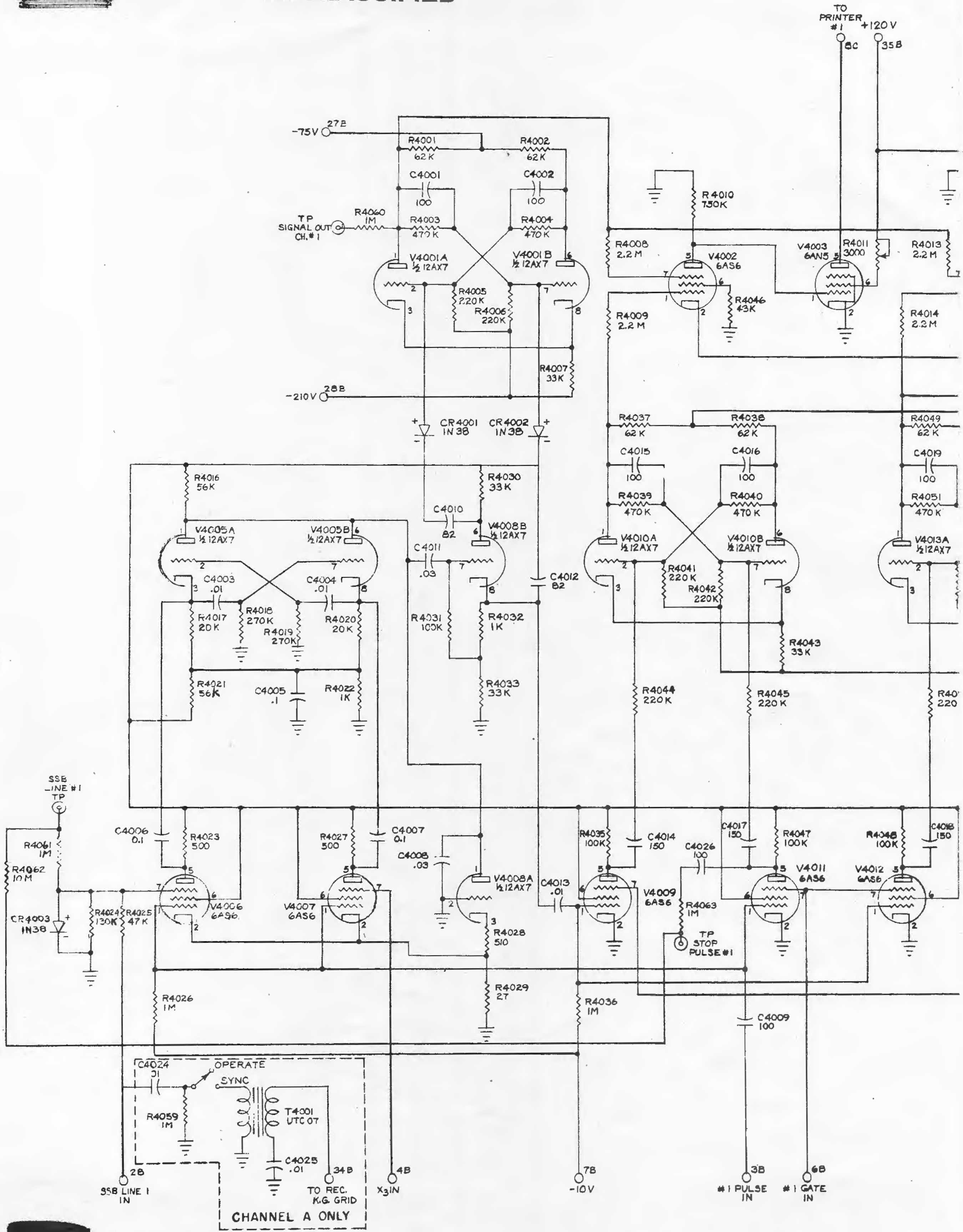

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Figure 14 - Receive Channel "A" - schematic diagram

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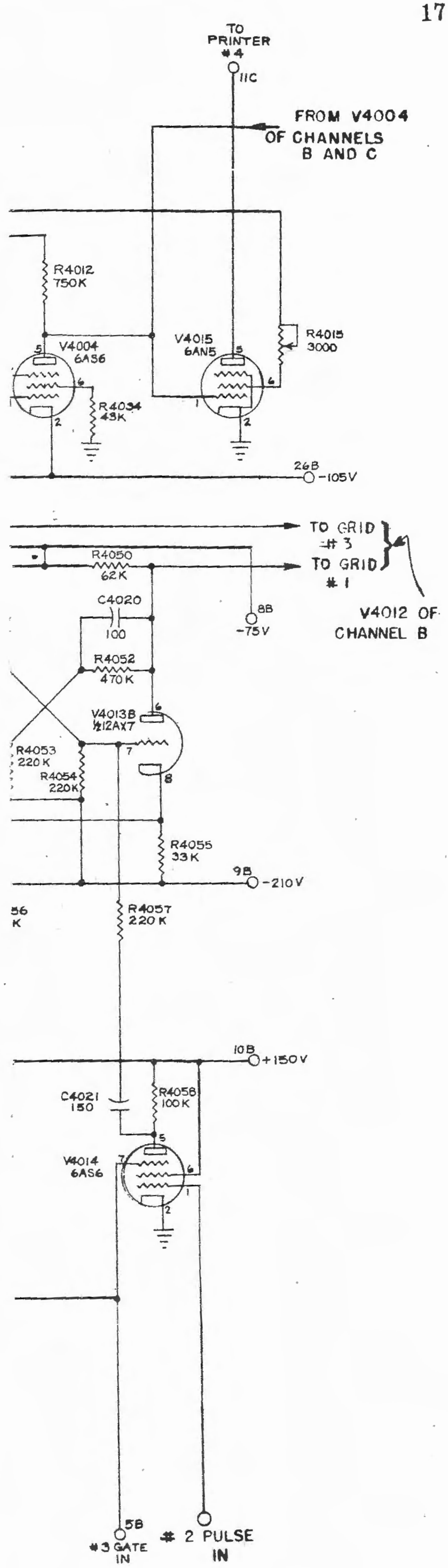
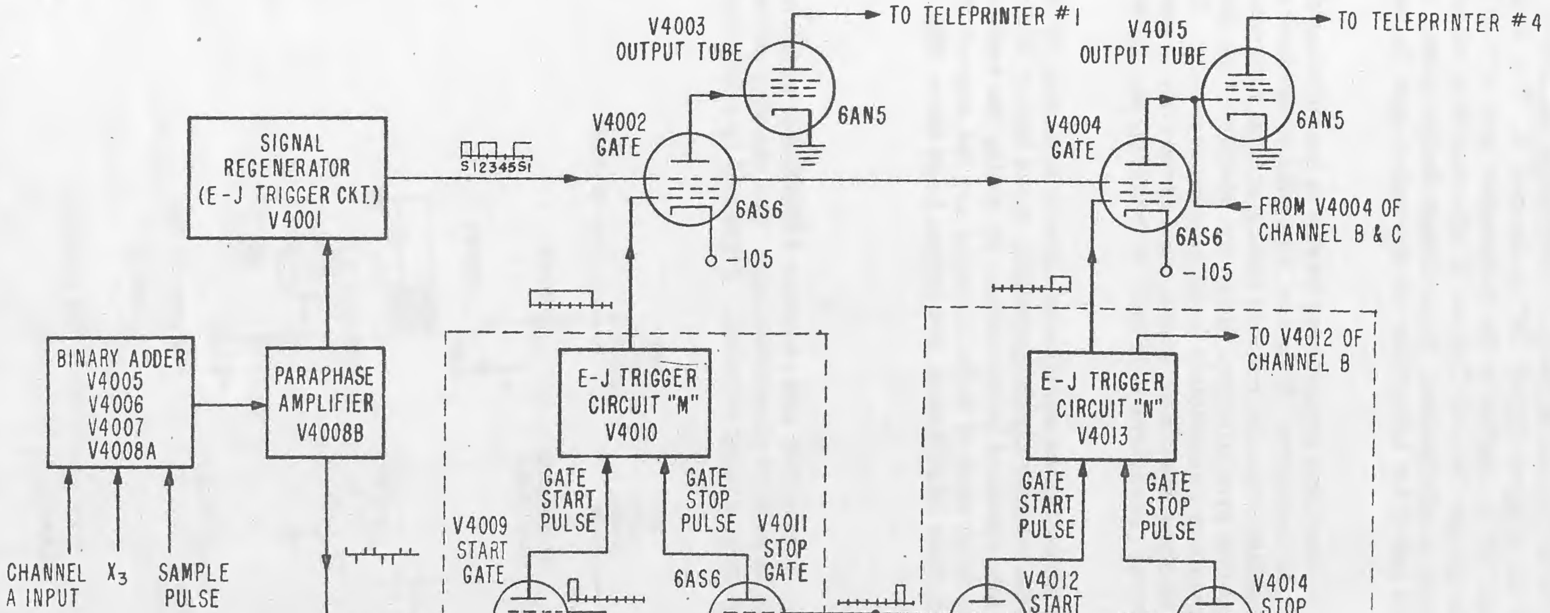


TO PRINTER #4
11C
FROM V4004 OF CHANNELS B AND C
R4012 750K
V4004 6AS6
R4034 43K
V4015 6AN5
R4015 3000
26B -105V
TO GRID #3
TO GRID #1
V4012 OF CHANNEL B
R4050 62K
C4020 100
8B -75V
R4052 470K
V4013B ½12AX7
R4053 220K
R4054 220K
R4055 33K
9B -210V
56 K
R4057 220K
10B +150V
C4021 150
R4058 100K
V4014 6AS6
5B
#3 GATE IN
2 PULSE IN



TO TELEPRINTER #1
V4003
OUTPUT TUBE
6AN5
V4002
GATE
6AS6
-105
SIGNAL
REGENERATOR
(E-J TRIGGER CKT.)
V4001
S12345S
V4015
OUTPUT TUBE
TO TELEPRINTER #4
6AN5
V4004
GATE
6AS6
-105
FROM V4004 OF
CHANNEL B & C
BINARY ADDER
V4005
V4006
V4007
V4008A
PARAPHASE
AMPLIFIER
V4008B
E-J TRIGGER
CIRCUIT "M"
V4010
GATE
START
PULSE
GATE
STOP
PULSE
V4009
START
GATE
V4011
STOP
GATE
6AS6
E-J TRIGGER
CIRCUIT "N"
V4013
TO V4012 OF
CHANNEL B
GATE
START
PULSE
GATE
STOP
PULSE
V4012
START
V4014
STOP
CHANNEL
A INPUT
X3
SAMPLE
PULSE

In the gate generator circuits of Channel B, the gate start pulse for V4012 is obtained from the differentiated output of the trigger circuit "N" in Channel A. The output of the opposite plate of the same circuit "N" is applied to the suppressor grid of V4012 through a delay circuit. This insures the proper flow of Channel B information to teleprinter #4 after the completion of the Channel A information. This circuit design makes the operation of the gate circuits in Channels B and C for teleprinter #4 dependent upon the reception of a start element in Channel A.

A disturbance on the radio or land-line circuit may result in the printing of errors. This is also true in normal teletype operation. However, since the teleprinters, as used with the AN/FGC-14, are synchronized from the receive timing unit, a disturbance on the received signals does not disrupt this synchronism. When the source of the disturbance is removed, therefore, the teleprinters immediately start to print correctly. Fast recovery is not characteristic of normal teletype operation, since, once thrown out of synchronism, an interval of time (perhaps several characters in length) is required for the teleprinters to regain synchronism.

In summarizing the receive circuits, the enciphered signals from the six SSB lines are combined with the output of the receive cipher generator in the binary adding circuits. The deciphered signals are fed into standard teleprinters. By gating the reconstructed signals, the proper two elements from each of three channels are fed sequentially into a common printer. In this manner, four teleprinters are driven from three SSB lines.

Key Generator Start Circuits

Synchronous operation of the transmitter and receiver AFSAX-500 requires that the key generators at both terminals be started simultaneously. The starting pulse for both key generators is initiated at the transmitting terminal. Figure 16 is a schematic diagram of the start circuits.

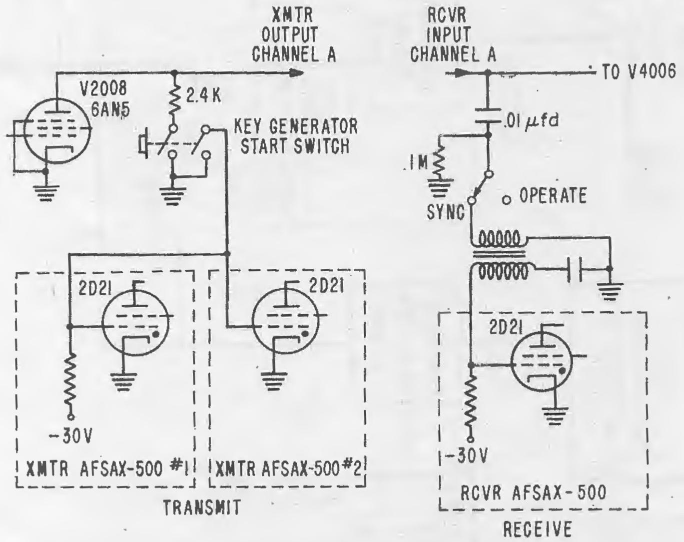


Figure 16 - Key generator start circuits—schematic diagram

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The start pulse for the receiver key generator is transmitted over Channel A. The source of anode voltage for the Channel A output tube, V2008, as well as for the output tubes in the other channels, is contained in the U.P. equipment. Prior to starting, space (no current) signals are sent over all channels. When the start switch is pushed, the line is grounded through a 2400-ohm resistor. This results in a mark (current) signal being transmitted over Channel A. At the same time, another section of the switch grounds the control grids of the thyratron start-tubes in the two transmitting key generators. The grids of these tubes are normally biased so that the tubes are not conducting. The thyratrons fire, and the transmitting key generators start operation.

At the receive terminal, the "sync-operate" switch is thrown to the "sync" position. The grid of the receive key generator start thyratron is biased so that the tube is not conducting. The mark signal received from the input line applies a large positive pulse to the grid of the thyratron. This signal overcomes the bias on the grid and the tube fires, resulting in the immediate starting of the receive AFSAX-500. The key generators are then brought into exact synchronism by means of the manual phasing controls at the receive terminal.

Transmitter Distributor Start Circuits

As was mentioned in a previous section, in order to obtain a synchronous flow of information without the necessity for storage, the TD commutator brushes are started synchronously for each character. This is accomplished by energizing the release magnet in the TD at the proper instant of time (Figure 17).

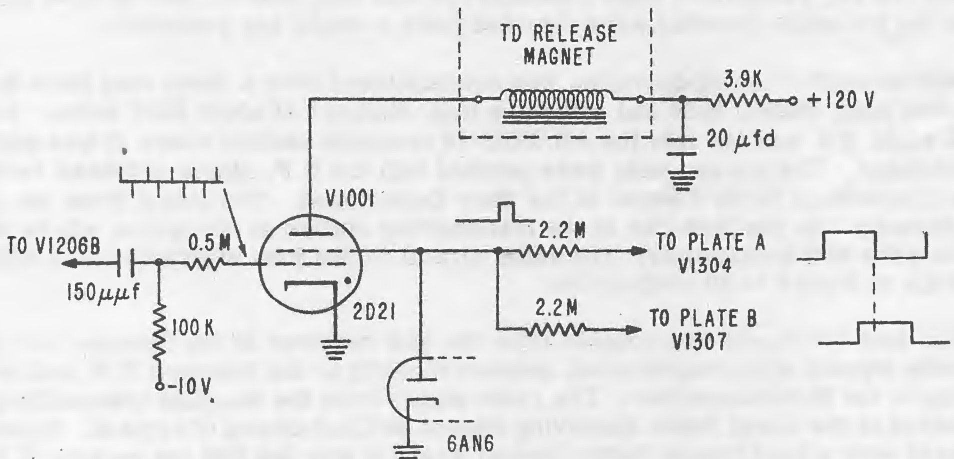

Figure 17 - Transmitter distributor start circuit - schematic diagram

A 20.8-millisecond gate voltage, derived by the proper addition of two square-wave outputs of the second ring-commutator in the transmit timing circuit, is applied to the shield grid of a type 2D21 gas thyratron. The tube is fired at the correct instant by the proper sampling pulse (from the first ring-commutator in the transmit timing unit) on its control grid.

Eight such circuits are incorporated into the AN/FGC-14 to provide for the sequential releasing of the eight TD.

TESTS, DEMONSTRATIONS, AND RESULTS

The laboratory model of the AN/FGC-14 was subjected to a brief preliminary test for the purpose of demonstrating to representatives of the various interested military departments and agencies the practicability of the system. It is planned that the preproduction models of the equipment will undergo extensive field tests in order to evaluate more adequately the operational use of the equipment.

The test installation was made at the Naval Communications Radio Photo Terminal at the Navy Department and the radio facilities of that activity and of Radio Central were utilized in conducting the tests. The installation consisted of the following equipment:

1	100-kc Frequency Standard
1	AN/FGC-14 Transmit Unit
1	AN/FGC-14 Receive Unit
2	Laboratory Model Key Generators
8	Teletype Transmitter Distributors
8	Teleprinters
2	Service Oscilloscopes

Since only two key generators were available for this test, both X_1 and X_2 (the cipher inputs to the transmit circuits) were obtained from a single key generator.

Complete eight-channel operation was accomplished over a radio loop from Washington, D. C. to San Juan, Puerto Rico and return—a total distance of about 3500 miles. Information from the eight TD was fed into the AN/FGC-14 transmit section where it was enciphered and multiplexed. The six channels were patched into the U.P. single-sideband terminal equipment located in Radio Central at the Navy Department. The output from the U.P. was coupled directly into the land line to the transmitting station at Annapolis, where it was used to modulate the SSB transmitter. The radio circuit to San Juan utilized normal SSB frequencies in the range of from 9 to 20 megacycles.

At San Juan the signal was coupled from the SSB receiver to the Receive U.P. where the mark-space signals were regenerated, patched directly to the transmit U.P., and fed through a land line to the SSB transmitter. The radio signal from the San Juan transmitting station was received at the Naval Radio Receiving Station at Cheltanham, Maryland. From there it was relayed over a land line to Radio Central where it was fed into the receive U.P. The output of the U.P. was patched to the receive section of the AN/FGC-14 where the information was deciphered and fed into the eight teleprinters.

Tests continued for about a week (April 5, 1952 through April 13, 1952) during which time the equipment was operated on the radio loop circuit a total of 20 hours. The existence of magnetic storms during the week of the tests provided an opportunity to observe the operation of the equipment under adverse conditions.

It was found that, once a usuable radio circuit was established, the starting of the key generators and the initial phasing of the equipment was a relatively simple matter, requiring

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only from two to three minutes. The test loop-circuit intensified the distortion of the radio signals relative to that which might have been expected in a one-way circuit.

Brief analysis of the copy obtained indicated that, on the whole, the copy was comparable to that obtained by normal operation of the teletype equipment. During severe radio conditions a lesser number of errors were observed in the copy obtained by using the AN/FGC-14. This can, of course, be attributed to the fact that a shorter time is required for sampling the signal in the AN/FGC-14 than in the teleprinters, and also to the fact that the AN/FGC-14 synchronizes the teleprinters locally rather than relying solely on the incoming signal. During one period exceptional radio circuits permitted errorless operation of all eight channels for a period of an hour and a half.

SUMMARY

It is anticipated that the AN/FGC-14 will prove its value mainly in large communication centers. One of the most obvious advantages acquired through the use of this equipment is the ability to handle large volumes of classified traffic. The long delays in the transmission of classified messages because of "pile-up" in the code room during times of high peak loads can be eliminated. The equipment would normally be operated continuously. However, it would also be expedient to operate the equipment as traffic demanded since only a few minutes are required to place the system in operation after a radio circuit has been established. The two extra channels available increase the traffic handling capabilities of the SSB system from 360 to 468 words per minute.

Traffic analysis on such a system would be possible only after breaking the code. The synchronous feature of the equipment makes it possible to encipher the start element of the teletype code and to eliminate the transmission of the stop element, thereby giving a monitor no indication of the beginning of a character. The headings of the messages, which are normally sent in plain text, would also be encrypted. Since the equipment operates on a continuous basis no suggestion would be given as to the number of messages sent, the length of these messages, or of their classification.

When fair to marginal transmission circuits are used, it is predicted that a noticeable improvement in the copy will be realized. The AN/FGC-14 requires less time for sampling the received signals than do the teleprinters. Synchronizing the teleprinters at the receive terminal results in the elimination of errors due to loss of synchronization. False starting of the teleprinters, because of atmospheric bursts on the received signals, will be minimized since the equipment will accept start signals only during a comparatively short period of each cycle.

The AN/FGC-14 electronically checks the accuracy and adequacy of the enciphering process before allowing the information to be transmitted. At the present time the accuracy of the encrypted information is checked manually in the code room.

The maintenance of the equipment is made easier because of the fact that the operation of each channel is relatively independent of the others, and because of the extensive use of a few basic electronic circuits.

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Mr. Fisk originated the over-all plans for the equipment, and many of the circuits used were "fathered" by him and Mr. Spencer during their development of the UXC-2 and the AFSAX-500. Many other people associated with the authors contributed their efforts during the construction stage of the development. The invaluable assistance and cooperation given by the officers and men of the Radio Photo Facility and of Radio Central at the Navy Department made possible the successful demonstration of this equipment. These included LCDR J. Greksouk, LCDR J. R. True, LT C. D. Scallorn, Mr. L. L. Griffith, M. M. Long, ETC, and R. C. Doyle, ET1. To these people and to many others, the authors are greatly indebted.

* * *

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