The Teletype Corporation receiving transmitter distributor

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ABSTRACT AND INTRODUCTION

In traditional teletypewriter nomenclature, a *transmitter* is a reader of perforated paper tape with an output in electrical (or mechanical) parallel form, not in the form of a serial teletypewriter signal. A *transmitting distributor* takes a parallel signal and serializes it into a serial teletypewriter signal. A *receiving distributor* takes such a serial signal and deserializes it into parallel form so that it can be decoded and then (usually) printed.

Ensuite, a *transmitter distributor* is a unit that reads a perforated paper tape and delivers a serial teletypewriter signal.

But a unit that looks like a familiar style of transmitter distributor, used in certain message encryption systems, has the paradoxical name "receiving transmitter distributor". What might that mean?

It actually in effect performs both receiving distributor and transmitting distributor functions. But it also reads an encryption *keytape* (which carries a string of random 5-bit "characters") and (aided by a single external relay) performs the classical *regenerative repeater* function and as well the classical "Vernam" encryption "mixing" for either encryption or decryption.

This article describes the operation and use of these special units. Background is given in important topic areas.

1 THE TELETYPEWRITER SIGNAL

1.1 The "start-stop" teletypewriter mode

The teletypewriters commonly seen in police stations, newsrooms, airline operations offices, corporate communication centers, and the like for many years used a 5-bit character code and operated over a binary channel in bit-serial form, in what would be called in today's taxonomy of data communication the *asynchronous mode* (but "in the day" it was described as the "start-stop" mode).

In this mode, in any given system design there was a defined maximum character rate, but characters were not necessarily continuously sent at that rate. Rather, after one character was sent, the next could begin at any later time consistent with that maximum rate. This of course fit well into the scenario in which the text was entered manually on a typewriter-like keyboard.

1.2 The character format

For historical reasons, the two states of the binary transmission channel are called "mark" and "space" The idle state of the channel, continuously in effect when no data was being sent, is *mark*.

When a character is sent, it begins with an interval of the *space* state, whose role wis to alert the receiving station that this was the beginning of a character. The duration of that "Start element" is "one unit", the *unit* being the unit (!) in terms of which the durations of elements are stated on a normalized basis. To put this into practical perspective, in one common system, the unit duration is 22.0 ms.

The Start element is followed by five intervals, of duration 1.0 unit each (the "Information elements"), which carry the five bits of the character's coded representation [1], being of state *mark* or *space* to convey the value of the associated bit as "1" or "0", respectively.

The character ends with a "Stop element", of the *mark* state. In the 5-bit teletypewriter system used in North America, for a curious historical reason, the duration of the Stop element is specified as 1.42 units.[2]

In figure 1, we see this format for two consecutive characters sent at the maximum specified character rate for the system in use.

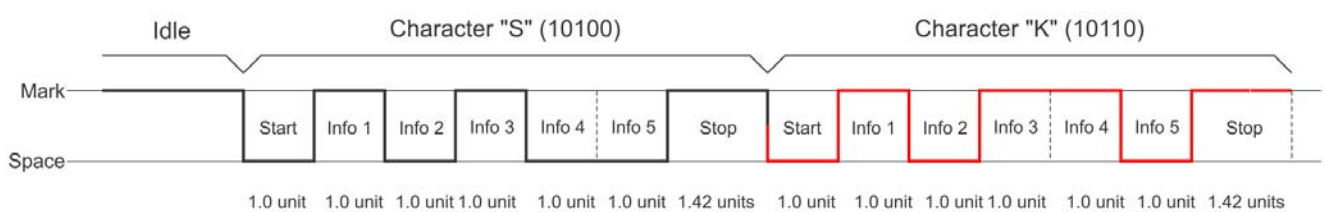

Figure 1. Teletypewriter signal–characters at maximum rate

The two characters ("S" and "K") were chosen so that, for both, bit 1 was mark (1) and bit 5 was space (0), so that the end of the Start element and the beginning of the Stop element could be clearly seen. The two colors of the mark-to-space transition between the two characters is just to remind us that this is the end of the first character (shown in black) and the beginning of the second (shown in red).

We start with the channel idle, in which it is in the *mark* state. The two characters than ensue as described just above.

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[1] The coded character set used was based on one developed by Donald Murray. But it is often, though erroneously, spoken of as the "Baudot" code, an *hommage* to French automatic telegraph pioneer J.M.E. Baudot, who developed a comparable, but totally different, coded character set.

[2] In the related international standard, the length of the stop element is specified as 1.5 units.

The period of the *mark* state that is the Stop element will of course be prolonged if the next character is not sent as soon as permissible (*mark* being the "idle state"). We see that in figure 2.

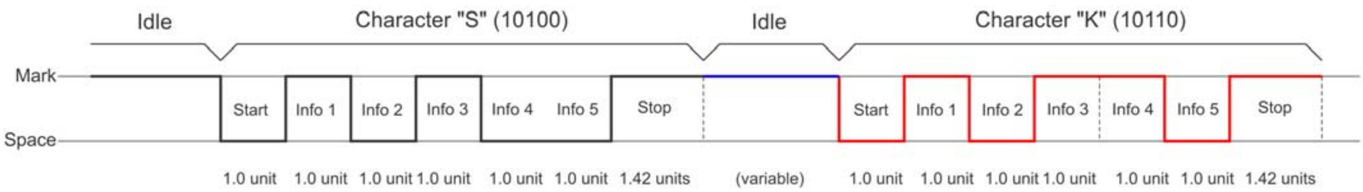

Figure 2. Teletypewriter signal–characters with idle period between

Again to put this into practical perspective, for the specific system mentioned just above, with a unit length of 22.0 ms, the maximum character rate is about 6.13 characters per second (ch/s) or about 368 characters per minute (ch/m).

We see in figure 2 that the Stop element of the first character (having the "idle" state) blends with the idle period (if any) between characters. Thus the Stop element can be looked at as enforcing a "minimum permissible idle period" between characters that are actually 6.0 units long (although the situation is not usually discussed that way). That outlook is shown (for both situations) in figure 3.

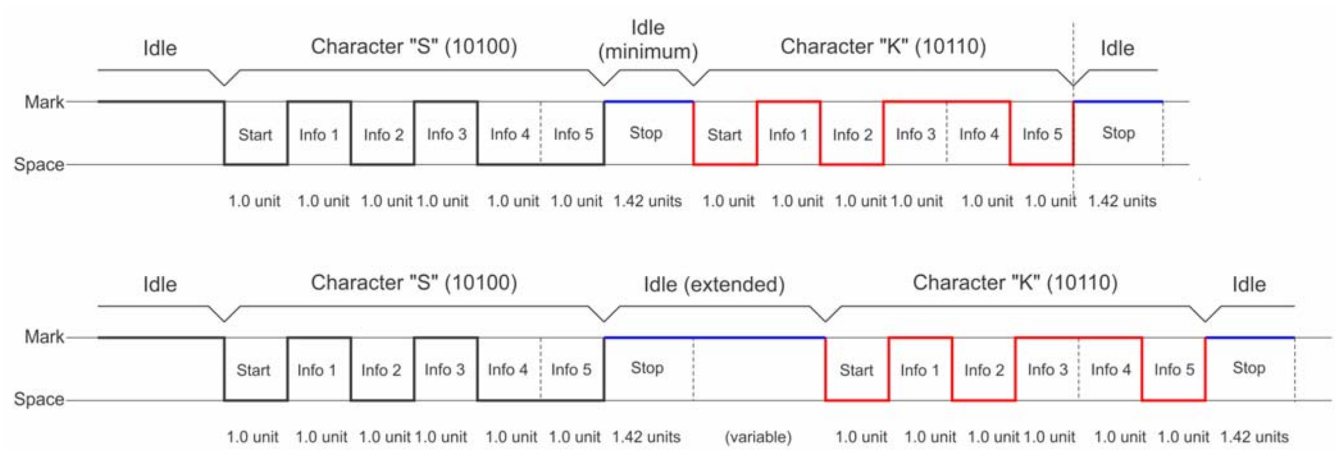

Figure 3. Alternate outlook on the Stop element

In the top timeline, we see the "idle" interval at its minimum permissible value (namely the duration of the Stop element). In the second timeline, it has been extended by the delay in commencement of the second character.

1.3 The modulation rate

With a format such as this, the critical property affecting whether the transmission channel would be able to handle a signal train of a certain speed is the duration of the shortest element of which the signal is composed. In most cases, it is the inverse of this minimum duration that is cited or specified (the value then of course increasing with the rate at which characters are sent).

This property is called the *modulation rate* of the signal, and is denominated in the unit *baud* [3], which is an *inverse second* (s^{-1}). Often the term "baud rate" is used for "modulation rate". For a unit length of 22.0 ms, the modulation rate is about 45.45 bauds.

2 THE VERNAM ENCRYPTION SYSTEM

The Vernam encryption system is named in honor of Gilbert S. Vernam, who was with an AT&T organization that later became Bell Telephone Laboratories. In perhaps 1918 he developed a practical execution of a previously-known encryption concept, cast in the context of a five-bit teletypewriter system transmitting over a conventional teletypewriter transmission channel.

Encryption is performed character-by-character. At the sending end, each character of the *plaintext* message (the actual message to be conveyed), represented by a five-bit binary word, is combined, bitwise *exclusive OR* (XOR), with the five bits of a *key "character"* [4], classically read from a 5-bit perforated paper tape (the *keytape*), to form a "character" [4] of the encrypted message (the *ciphertext*), to be sent over that channel. The keytape is advanced by one character for each plaintext character to be encrypted. The sequence of key characters on the keytape is sometimes called the "keystream".

This process is often described as "mixing" the two "character" streams.

The sequence of key characters, determined in advance (off-line) and punched into the keytape, is intended to be random (or pseudo-random but in a way that very closely follows the statistics of a random sequence).

At the intended receiving station(s) there is an exact copy of the keytape used at the sending station (typically delivered in physical form by a highly-secure courier).

As each character of the ciphertext is received, it is deserialized and the resulting five-bit binary word is combined, bitwise XOR, with the five bits of a key character read from the keytape to form a character of the recovered plaintext message. These characters are formed into a serial teletypewriter signal, which is eventually presented to a teletypewriter printer for rendering on a printed paper strip or page.

Clearly, it is vital that the keytapes at the sending a receiving stations be initially set to the same point for each message and that no transmission misadventure causes them to get out of synchronization.

Properly, no keytape (or section of a long keytape) is used more than once. Because of that dictum, this system is often characterized as a "one time tape" (OTT) encryption system. In some systems, the keytape readers had a knife blade

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[3] Named in honor of you-know-who.

[4] I put "character" in quotes here since the five bits do not represent an actual character in a coded character set.

that slit the tape lengthwise after it had passed through the reading “gate” to assure that the same keytape section was not used more than once.

It can be rigorously demonstrated that, if we put aside any possibility of “leaks” from the sending apparatus, if the keystream is truly random, and if the accepted protocols for the construction of the keytapes and their handling and use are followed scrupulously, this encryption system is “unbreakable”. That is, an adverse party, having intercepted the transmitted ciphertext, cannot, by any amount of laborious analysis, recover the plaintext message.

This system concept forms the heart of numerous other encryption systems.

But, as we will see, it is used in almost exactly the form I described in one military secure communication system (from the “World War 2” era and used well beyond).

It is important to note that, in encryption, the “mixing” of the plaintext with the keystream to give the ciphertext follows the same algorithm used, in decryption, for the “mixing” of the arriving ciphertext with the keystream to give the recovered plaintext. Thus, conceptually at least, the same apparatus could be used for the encryption and decryption functions (if at each end properly embedded in the overall communication system).

3 THE TELETYPE CORPORATION MODEL 14 TRANSMITTER DISTRIBUTOR

3.1 Terminology

In the traditional parlance of the teletypewriter field, *transmitter* refers to a reader of perforated paper tape with an electrical or mechanical output, but in parallel form, not in the form of a serial teletypewriter signal. A *transmitting distributor* takes a parallel signal and serializes it into a serial teletypewriter signal. A *receiving distributor* takes a serial teletypewriter signal and deserializes it into a parallel signal, which might then be decoded and printed.

Not surprisingly a *transmitter distributor* combines a perforated paper tape reader (transmitter) and a serializer (transmitting distributor, the “transmitting” being implied here) into a unit that reads perforated paper tape and sends the characters on it as a serial teletypewriter signal.

3.2 The “Model 14” transmitter distributor

An important product of Teletype Corporation for many years (familiar to teletypewriter operators and aficionados) was a line of transmitter distributors (with myriad variations) described, in terms of the nomenclature used for them in the Bell Telephone System, as the “Model 14 Transmitter Distributor”.

Figure 4 shows a typical one.

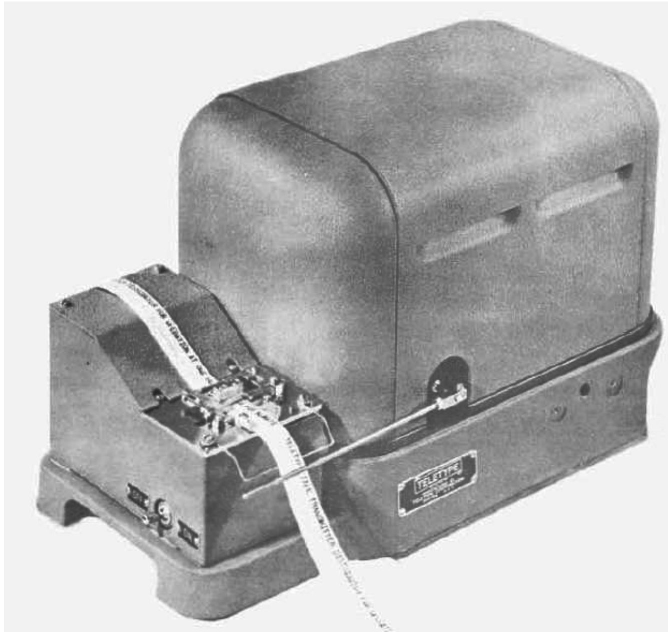

Figure 4. Typical Model 14 Transmitter Distributor

4 ABOUT THE TERM "DISTRIBUTOR", ANYWAY

The term "distributor" is an interesting one, and in fact is not strictly wholly apt for one of its two symmetrical uses.

In figure 5, we see a conceptual drawing of a hypothetical teletypewriter system.

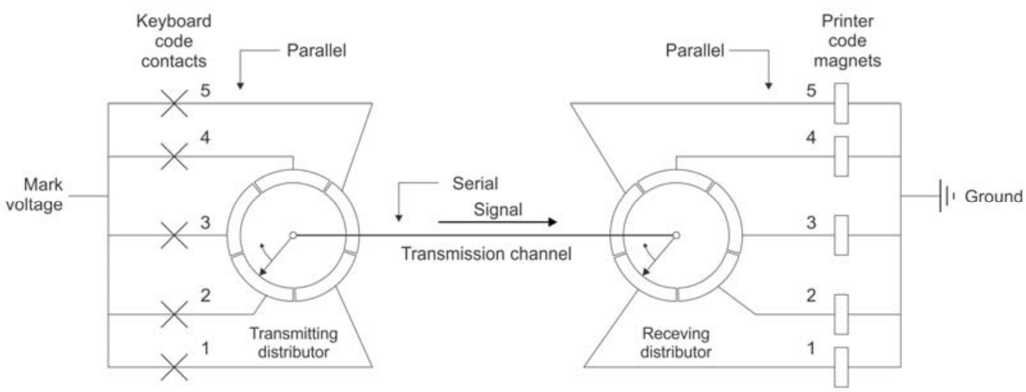

Figure 5. Hypothetical synchronous teletypewriter system

To make the drawing simpler, this is not a start-stop (asynchronous) system but rather a *synchronous* system. In such a system the transmitting and receiving distributors rotate continuously, and are kept in synchronization in a way we need not discuss here. This drawing presumes a direct keyboard sending arrangement.

If there is no "character" presented to the transmitting distributor (no key has been pressed on the keyboard), the transmitting distributor sends out the "all zeros" character ("null", or in teletypewriter terminology, "blank") which the receiving apparatus just ignores.

At the sending end (left), the distributor "picks up" the voltage (mark, or by default space) for each of the five bits from the keyboard and sends them out sequentially, 1 through 5, as elements of the transmitted character.

At the receiving end (right), the receiving distributor directs each of the five bit values (based on their time position in the overall sent character) to the corresponding code magnet of the printer. These code magnets then operate a decoder mechanism that causes the indicated character to be printed.

In other words, the receiving distributor *distributes* the five bit values to the five printer code magnets. Aha! Hence its name, "distributor".

But what about the transmitting distributor. It does not "distribute" the five bit values.[5] Rather it *collects* them (sequentially, to form the serial signal).

So then, why is it called a "distributor"? Presumably because it looked a lot like the receiving distributor. If it looks like a duck...

So one might argue that "transmitting distributor" is not an apt term. But I didn't choose it.

5 A RECEIVING DISTRIBUTOR IN THE START-STOP SYSTEM

Figure 6 shows in idealized form a "faceplate"-style receiving distributor as used in a start-stop system (which is the kind of actual interest to us).

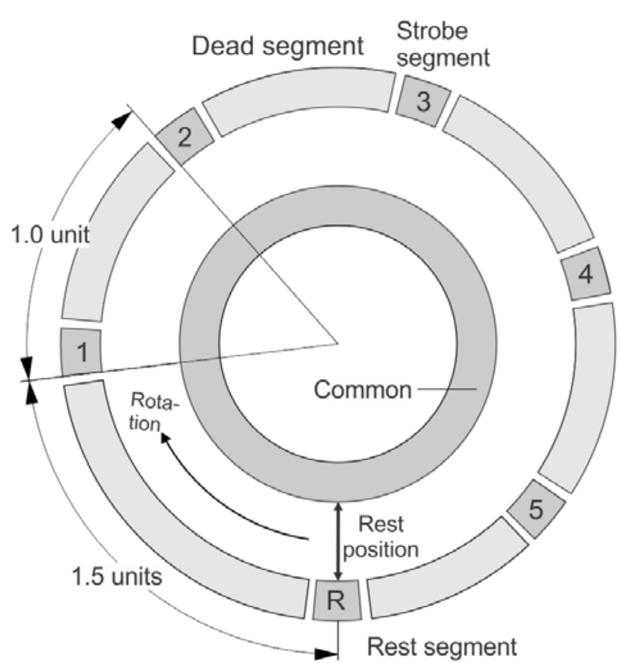

Figure 6. Idealized "faceplate" receiving distributor

[5] Thanks to teletypewriter historian Duncan Brown for reminding me of this.

We see the distributor wiper brushes (which would connect the inner "common" ring to the various segments in the outer ring[6]) in its rest position, where it would repose until the clutch/latch is released by the "release magnet" at the start of a character.

With the distributor in the rest position, the contact to the Rest segment prepares the circuit for that to happen as soon as the line state becomes *space* (from the start element of an arriving character). As soon as the brushes begin to rotate, and the brush moves off the Rest segment, that circuit is opened (as we do not want the release magnet operating and releasing as the line state changes during the character.

As the wiper first contacts the various "strobe"[7] segments (which ideally it does at the expected center of the respective Information element of the arriving character)[8], the state of the line (mark or space) is noted and captured somewhere (exactly where depending on what machine this distributor is part of).

The layout of the distributor is such that, ideally, the arm will reach the beginning of the "strobe" segment for Information element 1 exactly 1.5 units after the start of the character (where we would expect to find the center of that element). It reaches each of the succeeding strobe segments at intervals of 1.0 unit.

The speed of the distributor shaft is typically made about 14% greater than the maximum character rate. As a consequence, we expect the brush arm to arrive back at the Rest position about 6.5 units worth of time after the start of the character, or about 0.5 unit into the Stop element of the received character. If transmission is at the maximum character rate, the receiving distributor thus will stay at rest for (theoretically) 0.92 units of time (7.42-6.5).

Since the line state should then be mark, when the circuit to the release magnet is re-enabled (by the brush landing on the Rest segment), the magnet does not operate, and the distributor arm comes to a halt (until the start of the next received character).

In reality, the release magnet does not do its job instantaneously, and so when the Start element of the received character arrives, the commutator arm may not start to rotate instantaneously. To compensate for this, if we consider the receiving distributor faceplate seen in figure 6, we can adjust the distributor so the rest position is a little advanced within the Rest segment compared to the idealized position shown in the figure.

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[6] The segments labeled as "dead" in the figure have no electrical connection. Their purpose is just to give the brushes something of uniform height to ride over for their entire rotational journey.

[7] My term.

[8] It is often thought that the "strobing" somehow happens as the brush reaches the center of the "strobe" segment, but that is just not so.

6 THE REGENERATIVE REPEATER

6.1 The concept

Teletypewriter signals suffer distortion of their significant instants (the instants of transition between the two binary states of the signal) as they pass through lengthy transmission channels (in part caused by noise on the channels).

One way to avert corruption of the received messages due to this was to, after the signal has traveled some distance through a chain of transmission facilities, when the signal has been “corrupted” but not yet so much that the five bits of each character cannot be correctly discerned, deserialize the signal (using apparatus that essentially is a *receiving distributor*), store the five bits for an instant, and then from that “parallel” representation of the character (likely “correct”), generate anew a proper (perfectly timed) teletypewriter signal (using apparatus that essentially was a *transmitting distributor*).

By this process (potentially done several times over a very long transmission path), the accumulation of transmission timing errors was interrupted, resulting in a very low probability of the finally received message having character errors.

This entire apparatus was aptly called a *regenerative repeater*.

6.2 A consolidated implementation

The conceptual description above suggests that the receiving distributor and transmitting distributor in a regenerative repeater were independent organs.

But every time a received character begins, and the receiving distributor started to revolve to deserialize it, shortly after, the transmitting distributor had to start to revolve, to serialize the captured character.

Based on this reality, an alternative formulation was soon visualized. There was only a single distributor, whose speed of rotation was suitable for its first job, that of receiving distributor. As each information element was strobed (at what should be its time midpoint) to determine its apparent binary value, the state of the output channel was immediately set to that state (where it remained in force until the next information element was strobed). The outgoing line state was retained between strobe events by a bi-stable polar relay.

Something similar was done when the Start element of the reconstructed character should begin (the line state being then always set to space) and when the Stop element of the reconstructed character should begin (the line state then always being set to mark).

Thus the receiving distributor was also the collaborating transmitting distributor.

The distributor faceplate for this is just a little bit more complicated than that for a pure receiving distributor. Figure 7 shows an idealized one.

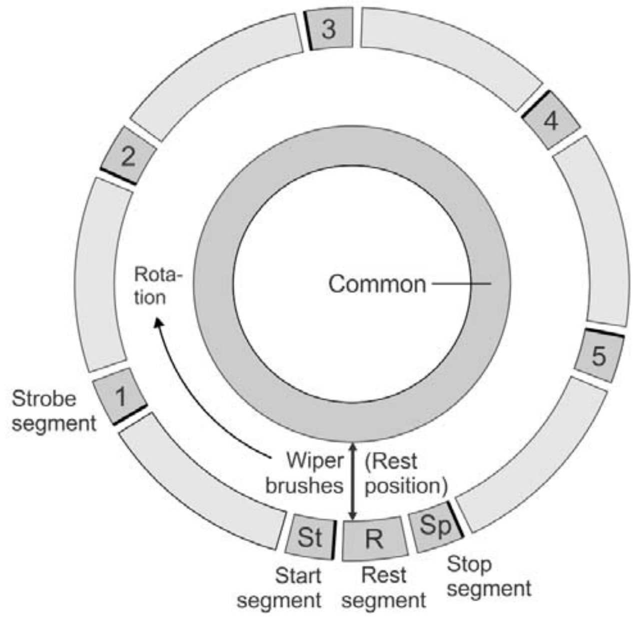

Figure 7. Idealized regenerative repeater distributor faceplate

The new ingredients, compared to the receiving distributor faceplate, are the "Start" and "Stop" segments. Their purpose is not to strobe the incoming signal at those points in time (a "receiving distributor" function, and not needed here since the incoming signal should have a known state at those points), but only to create the beginning of the Start and Stop elements of the outgoing signal (a "transmitting distributor" function).

A second distinction from the normal transmitter distributor is that here the release magnet mechanism (which in this case releases the distributor arm to start rotating at the beginning of each incoming character) is more sophisticated (in the interest of a more consistent operate time).

Figure 8 shows the operation timeline of a regenerative repeater based on this principle.

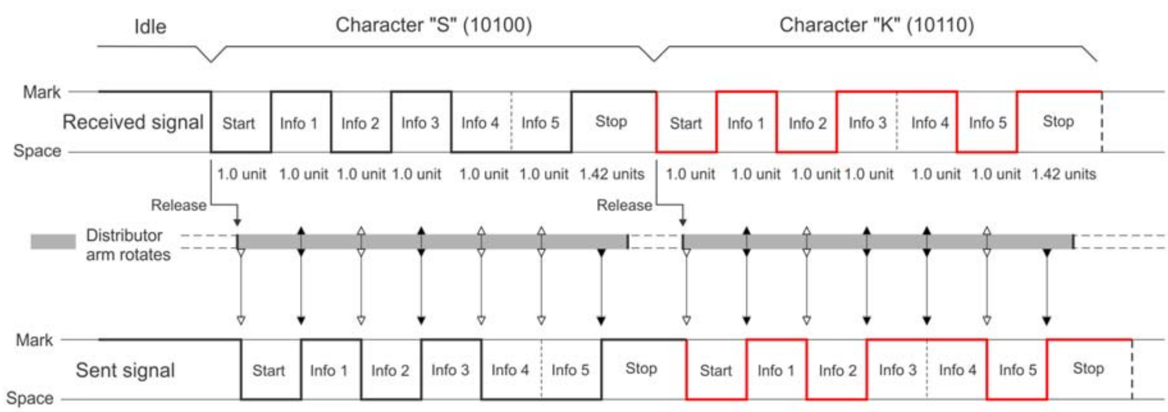

Figure 8. Regenerative repeater timeline

Certain details, which might happen one way or the other depending on the specific design, are not shown here exactly as they would be done with the units under discussion, in order to clarify the principle involved.

At the top we see the received signal for our familiar “message”, the characters “S” and “K”, here sent at the maximum character rate.

We start with the line idle and the distributor arm held by the release latch in its Rest position (indicated by the black stripe at the end of the shaded bar representing distributor arm rotation), which is on the Rest segment of the faceplate. That enables the circuit to the release magnet so it will be energized if the incoming signal state becomes space.

When the line state changes to space (at the start of the Start element of the incoming character), the release magnet is energized. After a slight delay, it operates and releases the latch, allowing the distributor arm to begin rotating. and the distributor arm starts to rotate.

The arrowheads pointing upward represent where the distributor “strobes” the line, and the color (black for mark, white for space) shows its finding for the example characters here. The arrowheads pointing downward show where the state of the “output” line is changed. This leads to the lower “Sent” signal waveform.

Those arrowheads that are paired with the “strobe” arrowheads above mimic the finding of the distributor’s findings in “strobing” the incoming line. Those not paired with a “strobe” arrowhead always set the outgoing line state to the indicated value independent of any strobing of the incoming signal.

When the arm reaches the Start segment, which ideally will be in the center of the Start element of the incoming signal, the state of the output line is changed to space (to begin the Start element of the outgoing character).

When the arm reaches the points where the line is strobed (which should be at the center of the various information elements of the incoming characters), the state of the output line is changed according to the findings of each “strobe” operation, this setting the output line state for the beginning of each information element of the outgoing character accordingly.

When the distributor arm reaches the Stop segment, the state of the outgoing line is set to mark, creating the beginning of the Stop element of the outgoing character (which persists until the start of the subsequent character).

A little while later, the arm reaches the Rest segment, which re-enables the release magnet circuit. But since the incoming signal state is then mark (it is in its Stop element), the release magnet is nor energized, and the latch makes the distributor arm stop in the Rest position.

Note that if there had been modest deviations of the times of transition of the input signal from the ideal times (caused by various transmission impairments), the output character not only has all the correct bit values but also it is now “perfectly timed". It has been "regenerated" (and thus could encounter additional impairment during the next leg of its journey without becoming "unreadable"). And that is what a regenerative repeater ordinarily does for a living.

7 APPLICATION TO ENCRYPTION

The units described here, although built on a "Model 14 Transmitter Distributor" chassis, nevertheless had a *regenerative repeater distributor* faceplate (conceptually like that shown in figure 7). With the assistance of a couple of relays in a supplemental equipment unit it operates as a regenerative repeater, as described above. But its objective is not to reconstruct the proper timing of a distorted incoming signal.

Here there is an additional function beyond that of the calssical regenerative repeater.. At either station of an encrypted system of the "Vernam" type discussed earlier, the tape reader portion ("transmitter") of the unit reads the station's copy of the keytape section for the message. As each information element of the incoming signal was "strobed" by the distributor, its binary value was combined, XOR, with the corresponding bit of the current key "character". The resulting binary value is then used to change the state of the output signal.

Thus, at the sending station, where the input to this unit is the plaintext message, the output is the ciphertext message (both messages as serial teletypewriter streams). At the receiving station, where the input to this unit is the ciphertext message, the output is the recovered plaintext message (again both as serial teletypewriter streams).

Figure 9. Typical Model 14 receiving transmitter distributor

8 THE BEASTS AND THEIR NAMES

Because this unit is built on the "chassis" of what we have called a "Model 14 transmitter distributor", and actually generates a serial teletypewriter signal (a function we attribute to a “transmitting distributor”), but really revolved (!) around a “receiving distributor”, and thus could “receive” a serial teletypewriter signal, it was often (but not always) called a “receiving transmitter distributor”.

Figure 9 shows a typical one. We note how similar it appears to a conventional Model 14 transmitter distributor.

It was part of a higher-level entity that includes a large unit that was typically described as a “teletypewriter repeater-mixer” [9] (a wholly apt term). That entity was in turn used as part of various complete secure teletypewriter stations.

9 THE APPENDIXES

Appendix A reviews in context certain units of the types described above and some of the higher-level entities in which they were used. The Teletype Corporation, Bell Telephone System, and U.S. military nomenclature for specific items are given for reference

Appendix B explains the circuit and operation of the regenerative repeater with keytape reader and Vernam mixer, implemented with a receiving transmitter distributor.

10 IN CONCLUSION

So this device, only slightly different from the basic “Model 14” transmitter distributor, with only the assistance of two external relays, performs the task of a teletypewriter regenerative repeater with a keytape reader and Vernam mixer in the middle. An astounding piece of engineering!

Kudos to Teletype Corporation and Bell Telephone Laboratories.

11 ACKNOWLEDGEMENT

Great thanks to several members of the online forum of the International Conference on Cryptologic History for their assistance as I worked out various mysteries in this matter.

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[9] The relays I alluded to earlier were part of that.

Appendix A
Equipment items and nomenclature

A.1 INTRODUCTION AND CAVEAT

This appendix reviews in context certain units of the types described above and some of the higher-level entities in which they were used. The Teletype Corporation, Bell Telephone System, and U.S. military nomenclature for specific items are given for reference

This information has been gleaned from documents available on the Internet. Especially to me, no expert on equipment of this type, the information is often ambiguous or unclear. I cannot guarantee the accuracy of the information to follow.

Those with more knowledge than I about this equipment are certainly invited to inform me where I might have gone wrong.

A.2 THE RECEIVING TRANSMITTING DISTRIBUTORS

Five specific "receiving transmitting distributors", all in which would be considered in Bell Telephone System terminology to be within the "Model 14" family of teletypewriter equipment, have been identified.

A.2.1 Nomenclature systems

A.2.1.1 *Teletype corporation*

All three units here have Teletype Corporation designations beginning with "XD", which stands for the composite description "transmitter distributor" ("X" being a common abbreviation in the telecommunication field for "trans").

Although considered in the Bell Telephone System to be part of the "Model 14" teletypewriter equipment family, these units (like the more familiar transmitter distributors of this general design) were not considered by Teletype Corporation to be part of a "family". Thus, the designation prefix "XD" does not have at its beginning a "family" letter (which would have been "F" for the "Model 14" family).

The "XD" is followed by a number, which indicates a specific kind of unit, and that may be followed by alphabetic suffixes, which might indicate the color of the housing or the motor and gear arrangement in the unit.

In general, this alphanumeric designation is followed by a "noun descriptor", sometimes in the case of these units "receiving transmitter distributor" but in some documents "transmitter distributor" and in other documents "distributor".

In any case the alphanumeric designation is wholly unambiguous without this noun descriptor.

A.2.1.2 *Bell Telephone System*

In the context of the Bell Telephone system, these units were given "apparatus codes" beginning with "14", since (as described just above) they were there considered part of the "Model 14" family of teletypewriter equipment. The "14" is followed by one or more letters, which completed the alphanumeric part of the apparatus code.

The complete apparatus code also includes a noun descriptor, formally placed first, as, "Transmitter distributor, 14AB". But in "conversation", the whole apparatus code for that unit was usually spoken as "14AB transmitter distributor". In the units discussed here, that noun descriptor was probably always "transmitter distributor".

But unlike the case of the Teletype Corporation unit designators, here the noun descriptor is a vital part of the apparatus code. There might well have been any number of other wholly unrelated items, of diverse kinds, for which the alphanumeric part of the apparatus code was "14AB". There might be (and I just make these up) an "Amplifier, 14AB" and a "Bracket, mounting, 14AB".

A.2.1.3 *U.S. Military*

The U.S. military designations of the items described here are formed under several complex systems of which I know almost nothing. I will just state them as found.

A.2.2 The five players

The nomenclature of the five units of interest, in the three "systems" discussed above, is given in this table:

Teletype Corporation Nomenclature	Bell System Nomenclature	U. S. Military nomenclature
XD79EX Distributor	14AD TD*	Not known
XG79EY Distributor	14AB TD	TT-12/FGQ-1 RTD*
XD79EZ Distributor	14AA TD	TT-13/FGQ-1 RTD
XD95GW Distributor	14ABM TD	TT-25/FG TD
XD100GW Distributor	14ABM-1 TD	TT-21/FG TD

* TD = "Transmitter distributor" RTD = "Receiving transmitter distributor"

In the Teletype Corporation nomenclature, the suffixes EX, EY, EX, and GY describe differing motor and gear arrangements (all of which produce nominally 420 RPM at the distributor shaft), as follows:

- EX: 120 V DC motor, governed (2102 RPM, gearing 9:45)
- EY: 120 V AC motor, governed (2102 RPM, gearing 9:45)
- EZ: 120 V 60 Hz AC motor, synchronous (1800 RPM, gearing 7:30).
- GW: Like arrangement EY but includes a filter.

The XD95GW has an end of tape mechanism, which detects if there is tape in the "read gate" and if not stops the unit from operating.

The XD100GW has the end of tape mechanism and as well has a tape feed suppression mechanism (the description of which is beyond the scope of this article).

It is interesting that for the XD95GW and XD100GW units (presumably newer than the others in the chart), it was seemingly decided that the formal noun descriptor in the military identifiers would be "transmitter distributor" rather than "receiving transmitter distributor".

In encryption systems used by the U.S. Navy, the XD100GW (TT-21/FG) is designated "CSP-2699".

A.3 THE NEXT HIGHER ENTITY

A.3.1 Introduction

These receiving transmitter distributors (and I will call all of them that from here on) are a part used in connection with, a higher-level unit that in one case is (aptly) described as a "repeater-mixer". It has two main functions:

- It includes the two relays that augment the receiving transmitter distributor to create a regenerative repeater and Vernam encryption mixer (as discussed in the body of this article).
- It includes relays and other components to embed this repeater mixer into various kinds of teletypewriter stations so it can function, when desired, to provide encryption when sending, or decryption when receiving, or both.

A.3.2 Teletypewriter set 131B2

This device, whose name shown above is actually a Bell Telephone System apparatus code, was known in the military nomenclature system as Teletypewriter Repeater-Mixer AN/FGQ-1. It is a wooden table with a cabinet beneath. Inside the cabinet are a number of mounting plates with relays, resistors, capacitors, and other components, plus a power supply. It was often called, for short, a "B2 table".

A receiving transmitter distributor, called in the manual for the 131B2 a "Special TD" ("TD" is common shorthand for a transmitter distributor), or "SpTD unit", is mounted on the table top and connects to the innards with three plug-in cables (seen earlier).

Figure 10 shows a typical one, with an "SpTD" on the top.

Figure 10. 131B2 with "SpTD unit"

But an alternative to a receiving transmitter distributor of the type discussed here was a "crypto unit". This was most likely a TSEC/KW-2 (I'm not sure of its "noun descriptor"). It had a faceplate distributor much like that of the "SpTD unit" but, rather than reading the keystream from a keytape, it generated it internally with a rotor-based "key generator" system (the working of which is beyond the scope of this article). It was for all practical purposes functionally and electrically interchangeable with the SpTD unit.

In some applications, a more-or-less conventional "Model 14" transmitter distributor sat alongside the SpTD unit or crypto unit on the table top. This could be used to read a perforated tape carrying the plaintext message to be sent when the rest of the teletypewriter set with which the 131B2 was associated did not include a transmitter distributor.

A.3.3 Nommes de guerre

When using a one-time keytape, this cryptosystem (in the broad sense of an "encryption scheme",, not necessarily with this particular equipment) was code named PYTHON. When using a rotor-based key generator, it was code named GORGON.

The codename SIGTOT[10] (one of a series of code names for encryption equipments starting with "SIG") may have applied to the family of receiving transmitter distributors discussed here (at least in their roles as the "SpTD" in the equipment systems discussed here).[11]

A.3.4 Full-duplex operation

Some of the teletypewriter stations with which the 131B2 were used were capable of "full-duplex" operation, That is, separate messages would travel in both directions between two stations simultaneously. (This of course required a teletypewriter channel capable of supporting full-duplex operation.)

In such a case, two 131B2 units were used, one for each direction of operation, each with its own "Special TD" or "crypto unit", with another auxiliary unit used to properly interface them with the teletypewriter station proper..

A.3.5 The SSM-3

The SSM-3 (I am not sure of its noun descriptor—perhaps "mixer") was broadly a replacement for the 131B2. It was in a smaller, metal housing. It contained a more thorough set of switches for controlling its operation than the 131B2. It likely had less elaborate provisions for interfacing with the associated teletypewriter set proper (essentially just being introduced into the sending or receiving line).

The SSM-33 was in effect two SSM-3s in the same housing, providing for simultaneous encryption/decryption of both directions for full-duplex operation.

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[10] Some students of such things conjecture that the "TOT" part of "SIGTOT" is actually an acronym for "tape, one time".

[11] Thanks to crypto system historian Nick England of the International Conference on Cryptographic History for helping me to sort this whole matter out.

Appendix B
Theory of the regenerative repeater and mixer circuit

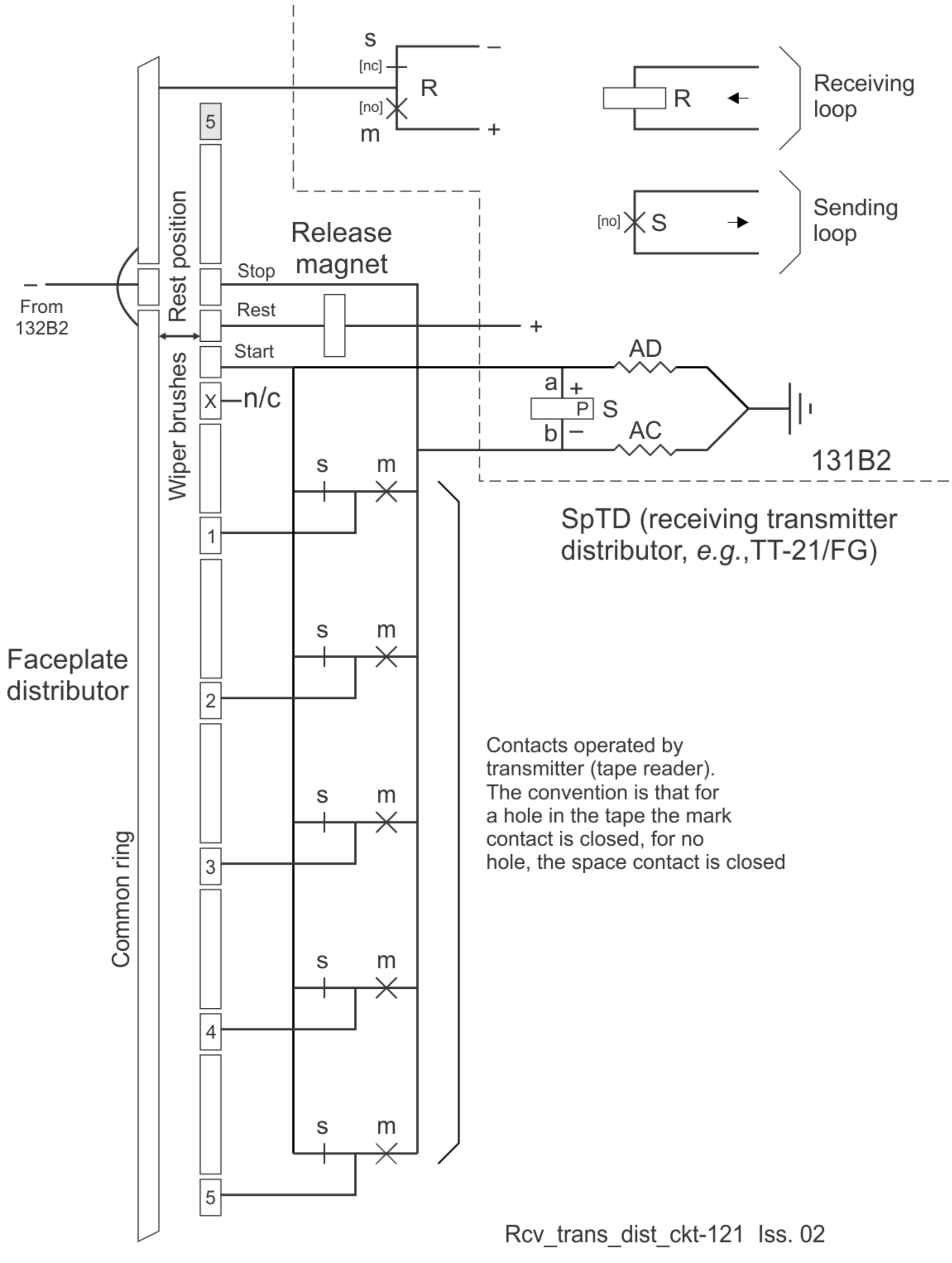

Figure 11. Simplified circuit

B.1 THE FIGURE

Figure 11 shows the circuit of a receiving transmitting distributor and the important circuit elements of the associated equipment unit (*e.g.*, a 131B2), simplified to allow the basis of its operation to be clearly seen. It presumes the use of an "SpTD unit"; that is, a receiving transmitter distributor of the type mostly discussed in the body of this article.

Relays R and S and the resistors flanking relay S are in the associated equipment unit (assumed to be a 131B2); everything else is in the "SpTD unit".

The distributor faceplate, actually in a circle, is drawn here "straightened out" to make the graphics more straightforward. The "strobe" segment for element 5 appears at the bottom but is repeated at the top (shaded), as a reminder of the cyclic nature of the distributor faceplate. The lengths of the segments and the gaps between them are not to scale..

The distributor segments to which no circuit paths connect are in fact "dead", present just so the distributor brushes always have something at the same height to ride on. The segment labeled "X" is not used in this application, and has no connection to the 131B2

B.2 NOTATION

Here I have used the "detached contact schematic" notation used on Bell Telephone Laboratories circuit schematic drawings beginning in the early 1950s. But, for the benefit of readers not familiar with that convention, I have also shown the familiar "nc" (normally closed) and "no" (normally open) designations on the various relay contacts.

B.3 RELAY OPERATE AND RELEASE CONVENTION

The preponderance of relays used in telephone switching circuits (and teletypewriter circuits, other than for handing the teletypewriter signal itself) are not polarity sensitive. When there is no current through the relay winding, the relay armature is "relaxed" and the relay is said to be *released*. When there is (sufficient) current through the winding, the armature moves, and the relay is said to be *operated*.

Almost invariably, the relays that handle teletypewriter signal are of the "polar" (polarity-sensitive) type. In some cases, this is because the signal itself is "polar", mark vs. space being indicated by the direction of current flow, and of coruse a polar rely is born to such a task.

In other cases, the teletypewriter signal is called "neutral"; mark is indicted by a certain current, and space by no current. Nonetheless, a polar relay is normally used to respond to that, its proper operating point being arranged by a controlled "bias" current through a second winding. One reason for the use of a polar relay in this situation is that the most familiar kind of polar relay is very quick in its response.

Because of its symmetry, there is no inherent physical concept of which state of a polar relay is released and which is operated.

But, for reasons beyond the scope of this article, the "idle" state of a teletypewriter signal is *mark*. As a result, in drawings of teletypewriter systems, it is common to consider that state of a polar relay handling a teletypewriter signal, with the line in the mark state, is released, and with the line in the space state, the relay is operated.

Especially when the signal is of the neutral form, this is counterintuitive: with current flowing through the relay winding, its state is considered to be *released*.

To avert this counterintuitivity, and for best clarity of the presentation (I hope), I will use the convention that all relays involved that receive or send a teletypewriter signal are considered to be *operated* with the teletypewriter signal in the *mark* state.

As a result, some of the voltage polarities used in figure 11 may not be consistent with the actual circuitry. (This is after all a tutorial illustration.)

In the transmitter (perforated tape reader) portion of the transmitter distributor, I consider the sensing contacts to be *released* when sensing no hole in the tape (space) and to be *operated* when sensing a hole (mark).

B.4 MARK AND SPACE ANNOTATIONS

In the figure, I have used the lower case letters "m" and "s" for mark and space to remind the reader of the sense of the sensing contacts and for other similar notation. I do this rather than using upper case letters so as to avoid confusion with the designation of elements of the S (send) relay, which I have designated as such for consistency with the actual equipment in which this circuit is used.

B.5 INPUT AND OUTPUT

In this tutorial figure, I assume that the input signal is presented to this circuit as a neutral loop signal (current flow for mark, no current flow for space), and that the output signal is also generated on a neutral loop basis, with the loop voltage being supplied elsewhere (so this circuit just closes a contact for mark and opens it for space).

B.6 THE CIRCUIT OF THE S RELAY

The S (send) relay is a bistable polar relay. It is considered to be put to its *operated* state when the when the voltage across it is consistent with the plus and minus markings on the winding symbol, and to its *released* state when the voltage across it is contrary to the plus and minus markings on the two ends of its winding. With no current through the winding, it remains in its present state (but see also section B.6).

We can summarize the conditions on the leads that go to points **a** and **b** thus:

At point a:

If the keystream bit is "0":
If the incoming bit is "1" (mark) then + voltage.
If the incoming bit is "0" (space) then – voltage.
If the keystream bit is "1":
0 voltage (through resistor AD).

At point b:

If the keystream bit is "1":
If the incoming bit is "1" (mark) then + voltage.
If the incoming bit is "0" (space) then – voltage.
If the keystream bit is "0":
0 voltage (through resistor AC)

The winding of relay S essentially observes the voltage of point **a** with respect to the voltage at point b. If **a** is positive with respect to **b**, the relay operates, and so the output bit will be "1" (mark). If **a** is negative with respect to **b**, the relay releases, and so the output bit will be "0" (space).

If we then consider the conditions shown earlier, we realize that, overall, in Boolean terms:

OutputBit = InputBit XOR KeytapeBit

which is exactly what is required by the Vernam encryption principle. This simple but clever circuit of a relay winding and two resistors performs the Boolean XOR function (the rest of the circuit cooperates to help it to do that, of course).

B.7 FORMING THE SERIAL OUTPUT SIGNAL

The S relay remains in whichever state it is put into by the voltage arriving across its winding. So if the circuit described just above determines that bit 1 of the output signal should be "1" (mark), the S relay and thence the output signal will be put into that state, and will remain so until something happens to the contrary.

If, one unit time later, the circuit determines that bit 2 of the output signal should be "0" (space), the S relay (and thence the output signal) will be put into that state, bringing to an end element 2 (mark) and commencing element 2 (space).

So, at least as far as the information elements are concerned, the output signal is constructed "on the fly" half a unit time later than the input signal, precisely timed ("regenerated"), and of course with the Vernam "mixing" having been performed.

B.8 OVERALL CIRCUIT OPERATION

We start with the line idle (in the mark state). Relay S is operated (put to that state at the end of the previous character). Relay R is operated by the mark line state, and puts positive voltage on the common ring. The distributor brush (in its rest position, as seen on the figure) connects that positive voltage to the Rest segment, which leads to the coil of the release magnet. But the other side of that coil is also connected to positive voltage, so the release magnet does not operate.

When the start element of a character (space) arrives, relay R releases and puts negative voltage on the common ring, and thus (as described above) to the coil of the release magnet. With the other side of the release magnet connected to positive voltage, the release magnet operates and releases the distributor arm, which begins to rotate.

The distributor brush almost immediately moves to the Start segment, sending that negative voltage to point **a** of the S relay winding, releasing S and beginning the Start element of the output signal.

One unit time later, the distributor brush contact Strobe segment 1. The voltage it puts to it depends on the state of relay R, which reflects the state of the input signal. That voltage works as described in section B.6 to put relay S into the proper state for element 1 of the output signal. Elements 2 through 5 of the input signal are strobed in the same way, resulting in the corresponding elements of the output signal..

One unit time after element 5 is strobed, the distributor brush connects negative voltage (always, because of the special segment of the common ring at that position) to the “Stop” segment, and that leads (always) to point **b** of the S relay winding, operating S and beginning the Stop element of the output signal (mark).

B.9 SO WHERE IS THE “MIXING” DONE?

In this field, when speaking of a “Vernam” encryption system, the process of combining the key characters with the plaintext characters (when encrypting) or the ciphertext characters (when decrypting), bitwise XOR, is often spoken of as “mixing”.

This might be done in parallel, with five XOR circuits working at once on the five bits of the two “input” characters, or it might be done serially, with one XOR circuit, one bit at a time, as the output character is formed as a serial teletypewriter signal. As we saw above, in the systems of interest here, it is the latter.

And, if we take the latter definition of “mixing”, it actually occurs at the S relay which, (assisted by its two flanking resistors, AC and AD) implements the Boolean XOR function.

And since the S relay (with those resistors) is not located in the receiving transmitter distributor itself, but rather in the associated equipment (*e.g.*, 131B2), it is normal (and justifiable) to say that in these systems the mixing is done by the 131B2 or such.

B.10 THE REAL CIRCUIT

B.10.1 Introduction

Of course, beyond the matter of the type of the R relay, in the real circuit there are various features not needed to illustrate the theory of operation, and accordingly are not shown in figure 11. But I will give some their due here.

B.10.2 Resistors, capacitors, and filters

These include resistors (some of which are to prevent dangerously large current flows in the case of an inadvertent “short circuit” on the exposed distributor faceplate) and capacitors used for various filtering purposes, as well as actual “filter” assemblies. These components are almost all in the associated equipment, rather than in the receiving transmitter distributor itself.

B.10.3 The R relay

Since, in the assumed interface context of the illustration, the R relay is not used to detect the polarity of the receiving loop current, for the sake of clarity I have shown it as if it were a *neutral* (that is not *polar*, meaning polarity sensitive) relay.

In reality, both the input and outputs of the part of the system shown in figure 11 are polar, and both relays S and R are of the polar type. And neither the input nor output of this circuit actually go directly to the two teletypewriter signal circuits, as the figure suggests. They are actually coupled to those circuits through other relays in the 131B2, which can be configured for those circuits operating on either a polar or neutral basis.

B.10.4 Bistability of the S relay

Another feature in the actual circuit has to do with the S relay being bistable. The operation of the system depends on the S relay remaining in the position to which it is put by the voltage on a Strobe segment until it might be put to the opposite state by the voltage on a later Strobe segment (or the Stop segment).

A polar relay of the general type used here **can be** adjusted so it is fairly robust about remaining in position when there is no current through the winding. Such a relay is often described as being “sticky”, and I suggested that this was the case for relay S in my description of circuit operation. But I fibbed a little.

In the 131B2, the polar relays used for R and S (and R1, of which I did not need to speak) are of the same type, and are plug-in interchangeable (these relays are a bit “fussy”, and might often need to be replaced by freshly-adjusted ones). For best interchangeability of the “inventory” of replacement relays, they are all adjusted the same.

But where one of these relays is used as the R relay. whose job it to distinguish mark from space when a character element is “strobed”, to avoid “bias” when it does that, the desirable adjustment does not make the relay very “sticky”.

So when that same type of relay is used as the S relay, with the standard adjustment used for all three of the polar relays, it is not, on its own, very “sticky”.

Therefore, in the actual system, when the S relay is in one state or the other, its contact causes a current to be sent through a second winding of S in such a direction as to explicitly hold the relay in that state. (This is not shown in the figures.) It is “made sticky” electrically.

B.10.5 Locking the R relay

When the state of the incoming signal is strobed at what should be the middle of an element (when the distributor wiper first contacts the pertinent “Strobe” segment), the state of the R (receiving) relay is locked in its present state by a circuit path not shown on the figure. This prevents irregular operation of the system in the case where the line state is “unsteady” (perhaps from noise or interference) at this time.

This also means that the often-heard notion that “the receiving distributor only pays attention to the middle 20% of each element” (this fraction based on the relative angular extent of the “Strobe” segment) does not really apply to this system. The circuit pays attention to the line state for an instant when the distributor brush first contacts the “Strobe” segment.

B.10.6 The “ground” on resistors AC and AD

Figure 11 shows the ends of resistors AC and AD going to “ground” (the “zero voltage” point). In reality, from the junction of those resistors the circuit passes through a winding of relay R (for the purpose described in section B.10.5) and then goes to a “zero voltage” point created by two equal resistors running to the positive and negative sides of the 110 V DC power supply (which actually has no “ground” connection).

But for our purposes, the simplification in figure 11 does not disturb our understanding of the operation of the S relay.

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