May 5, 1964 R. E. WILLIAMS 3,132,334

MIXED BASE CODE GENERATION

Filed July 24, 1958 7 Sheets-Sheet 1

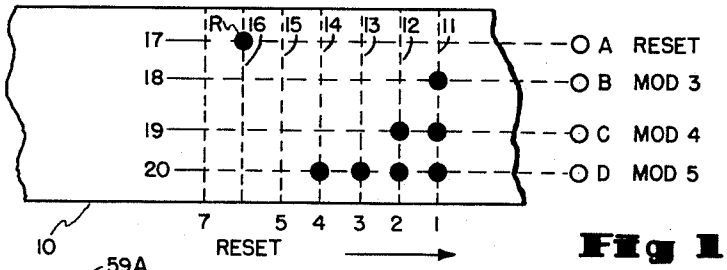


Fig 1

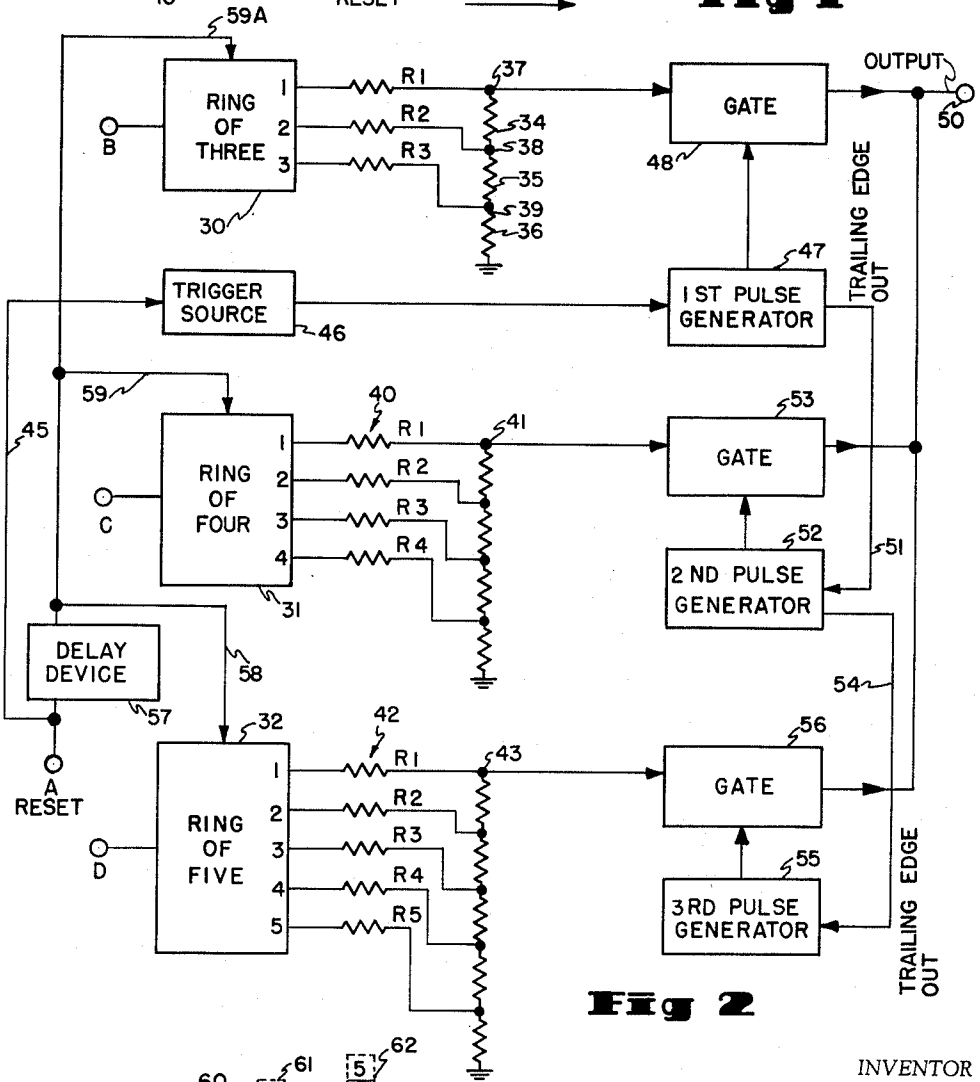


Fig 2

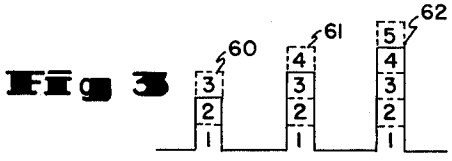


Fig 3

INVENTOR

RICHARD E. WILLIAMS

BY W. Robert Baylor
Hyman Kurwitz

ATTORNEYS

May 5, 1964 R. E. WILLIAMS 3,132,334

MIXED BASE CODE GENERATION

Filed July 24, 1958 7 Sheets-Sheet 2

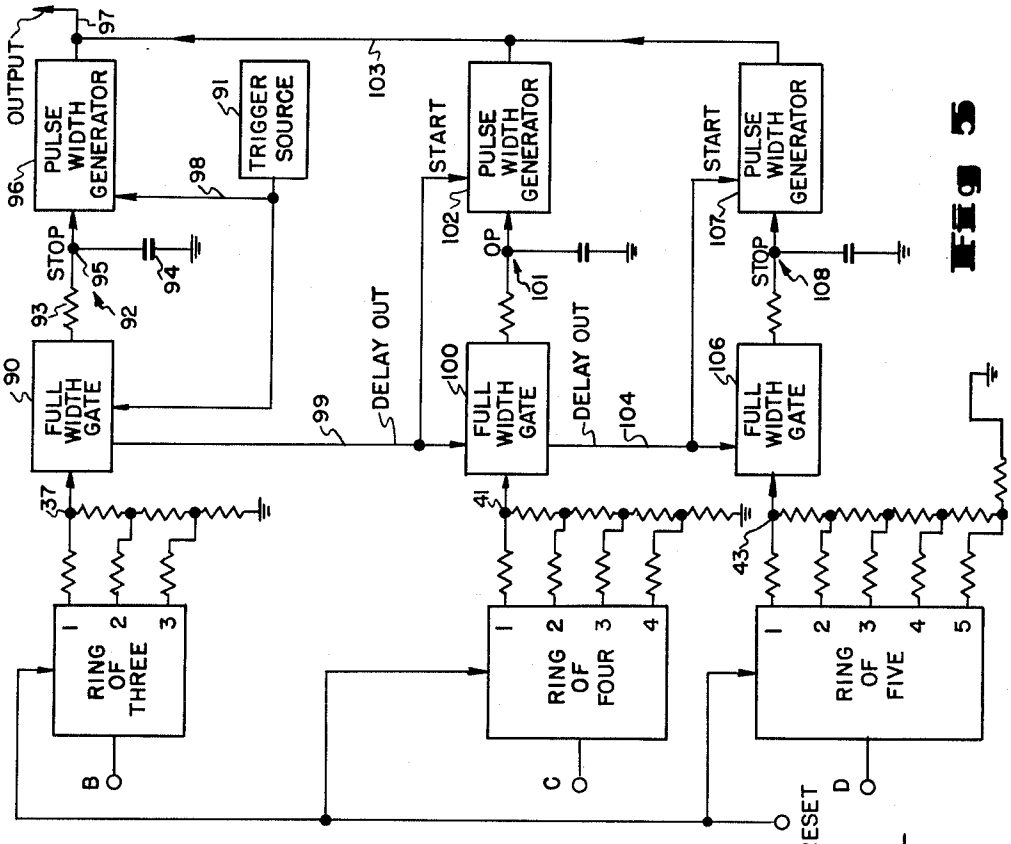


Fig 5

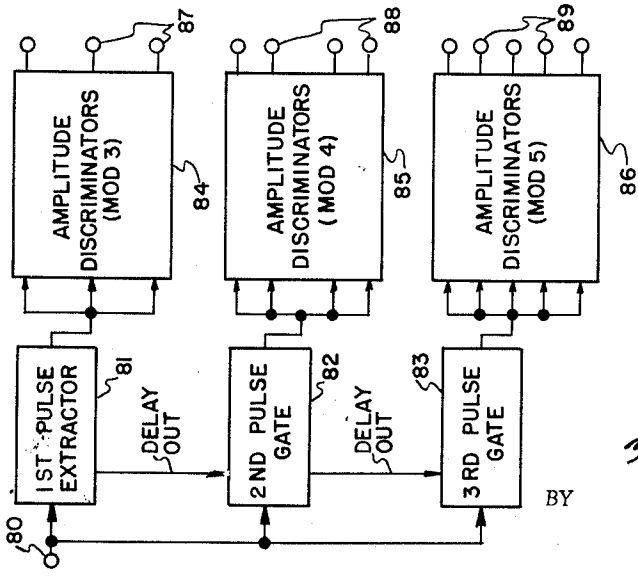


Fig 4



Fig 6

INVENTOR

W. Robert Baylor
Hyman Hurwitz

BY

ATTORNEY

May 5, 1964 R. E. WILLIAMS 3,132,334

MIXED BASE CODE GENERATION

Filed July 24, 1958 7 Sheets-Sheet 3

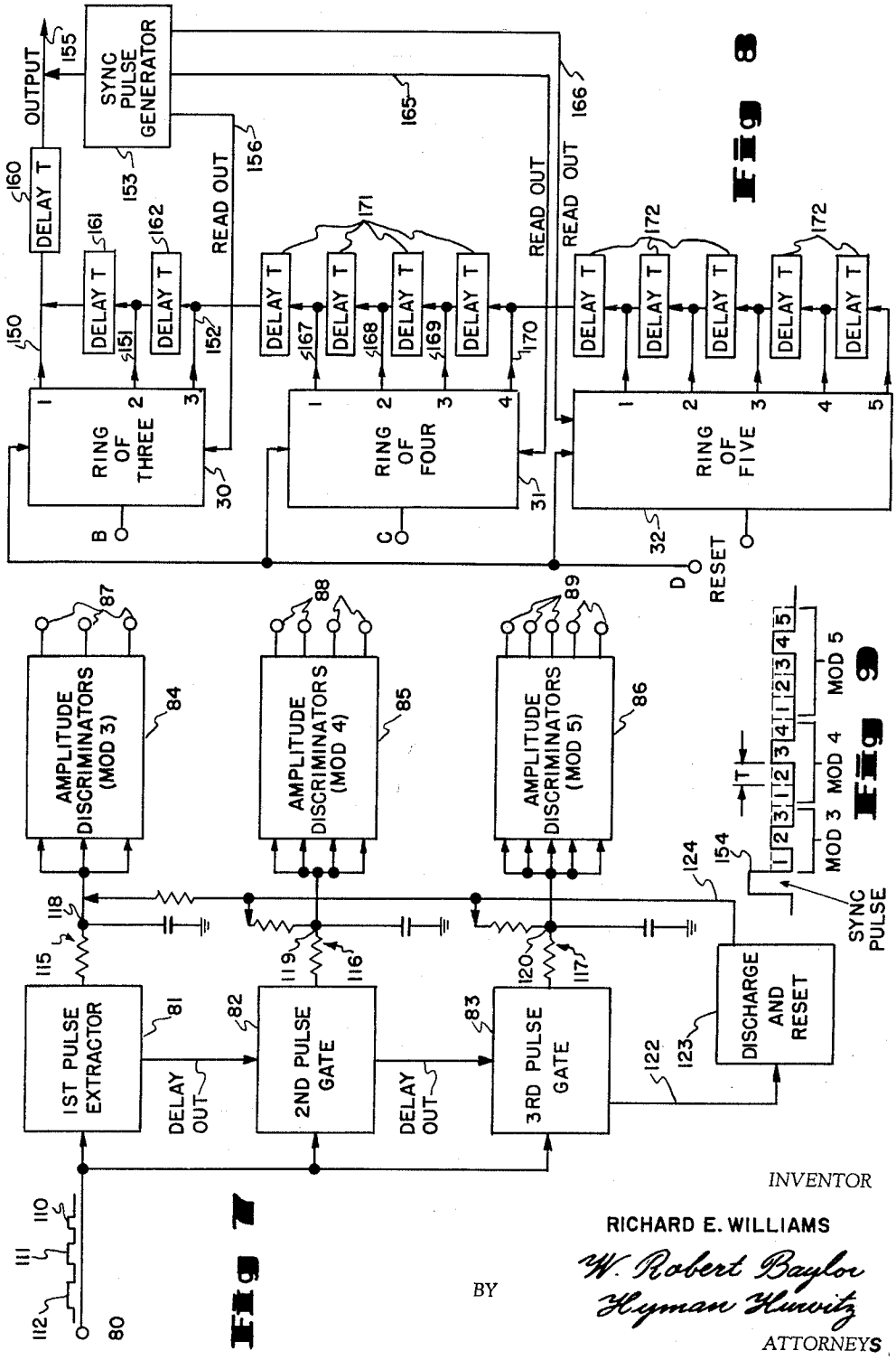


Fig 8

Fig 9

Fig 7

INVENTOR

RICHARD E. WILLIAMS

BY W. Robert Baylor
Hyman Hurwitz

ATTORNEYS

May 5, 1964 R. E. WILLIAMS 3,132,334

MIXED BASE CODE GENERATION

Filed July 24, 1958 7 Sheets-Sheet 4

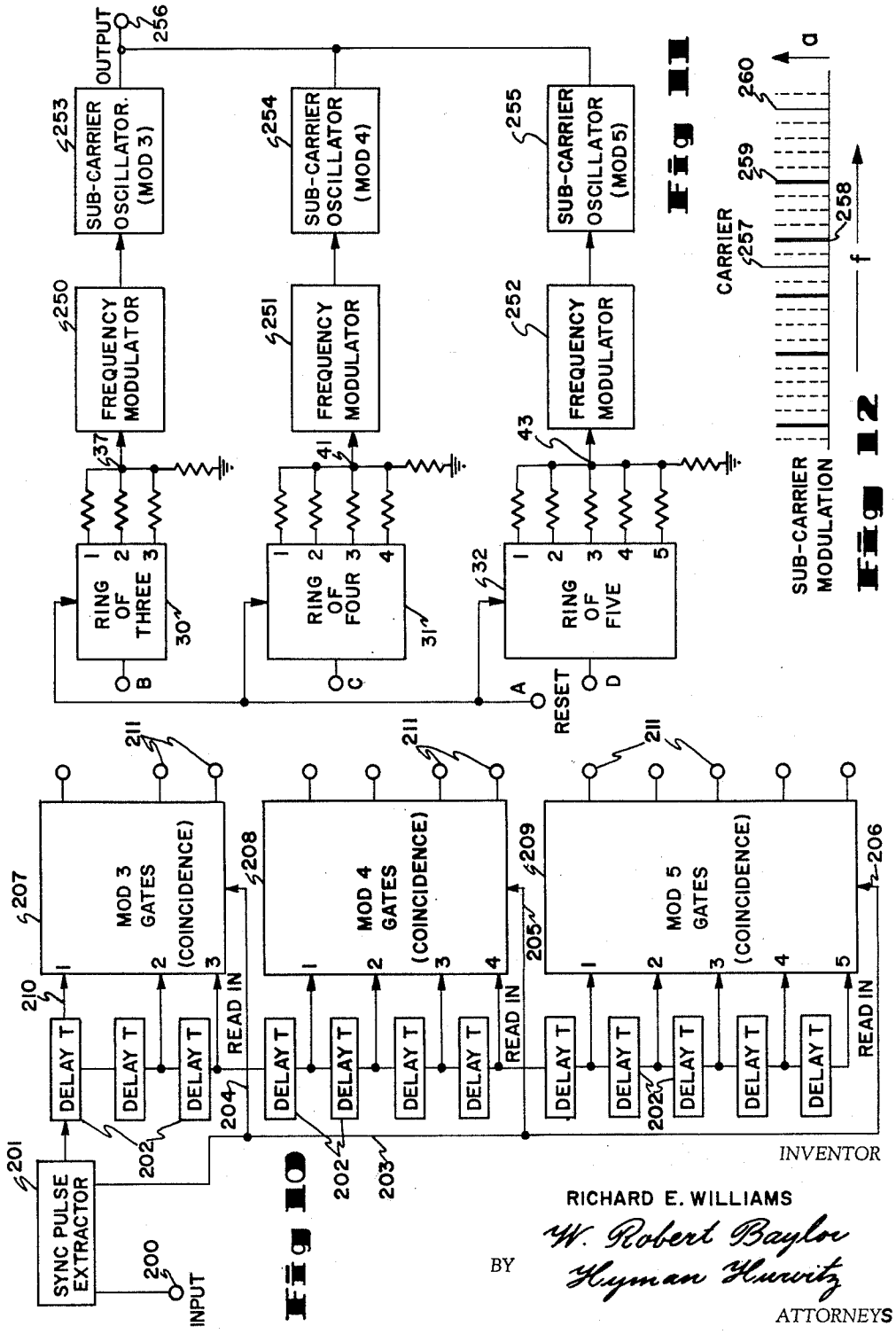


Fig 11

Fig 12

Fig 10

INVENTOR

RICHARD E. WILLIAMS

BY W. Robert Baylor
Hyman Hurwitz

ATTORNEYS

May 5, 1964 R. E. WILLIAMS 3,132,334

MIXED BASE CODE GENERATION

Filed July 24, 1958 7 Sheets-Sheet 5

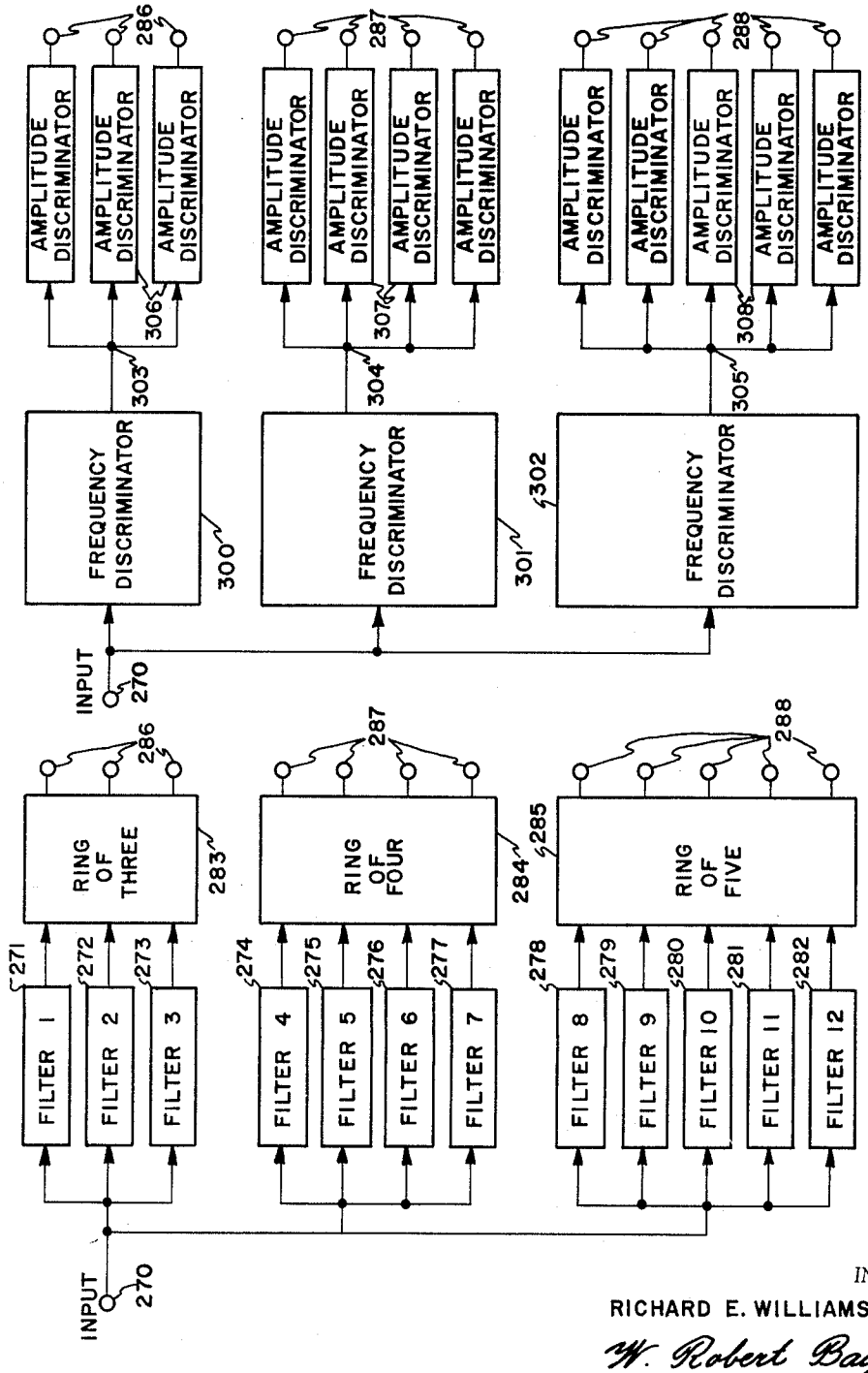


Fig 14

Fig 13

INVENTOR

RICHARD E. WILLIAMS

BY W. Robert Baylor

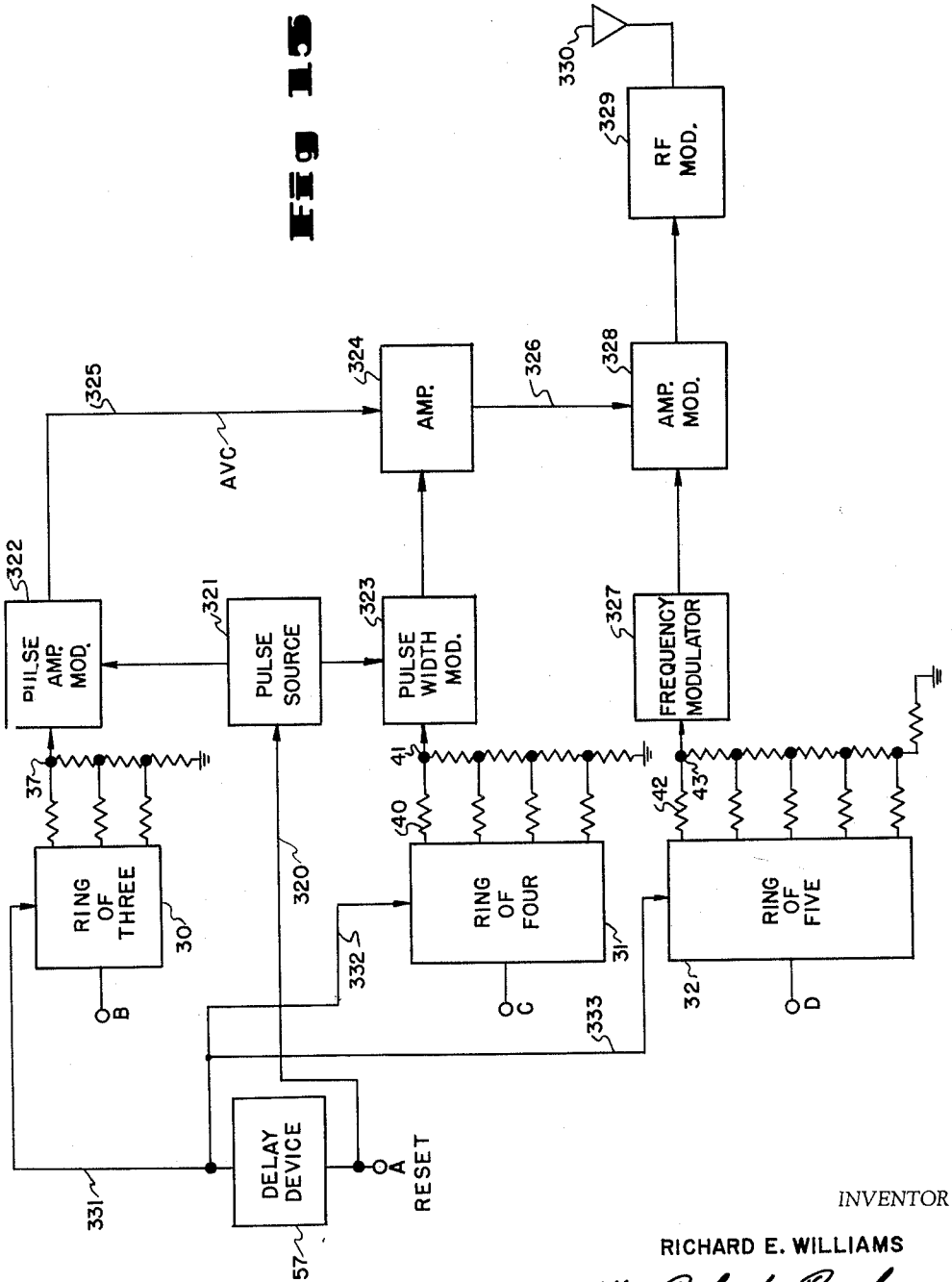
Hyman Hurwitz

ATTORNEYS

MIXED BASE CODE GENERATION

Filed July 24, 1958 7 Sheets-Sheet 6

Fig 15



INVENTOR

RICHARD E. WILLIAMS

BY W. Robert Baylor
Hyman Hurwitz

ATTORNEYS

May 5, 1964 R. E. WILLIAMS 3,132,334

MIXED BASE CODE GENERATION

Filed July 24, 1958 7 Sheets-Sheet 7

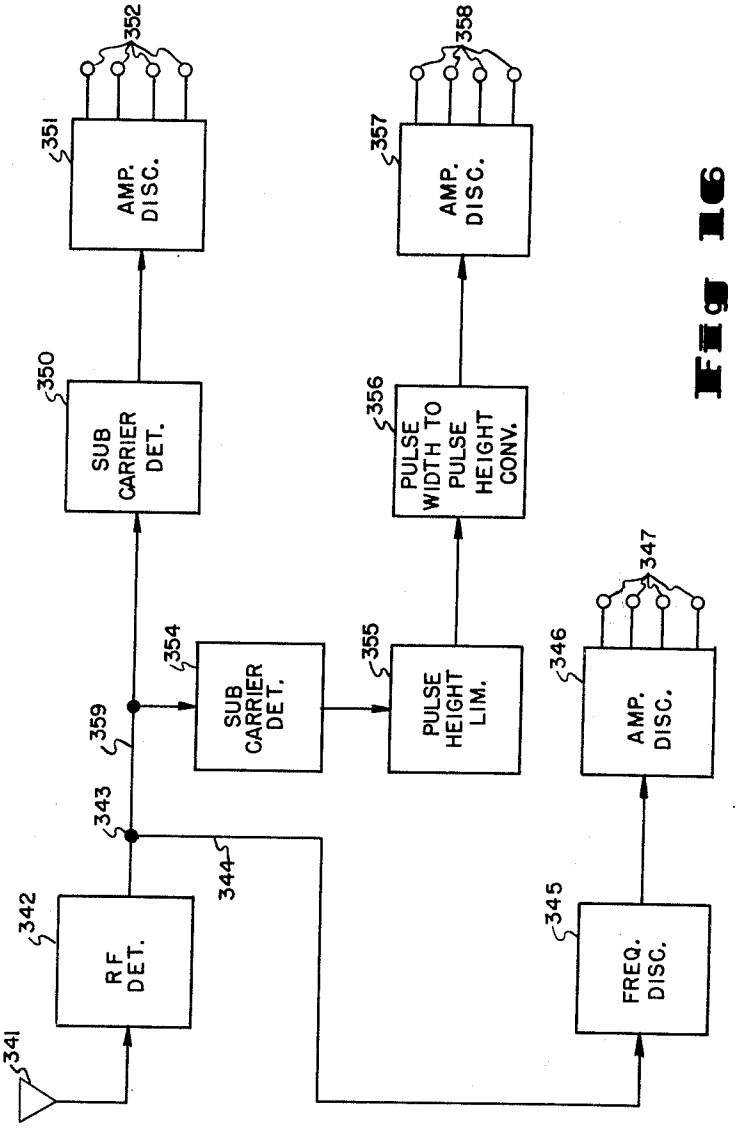


Fig 16

INVENTOR

RICHARD E. WILLIAMS

BY W. Robert Baylor
Hyman Kuwitz

ATTORNEYS

United States Patent Office 3,132,334 Patented May 5, 1964

3,132,334

MIXED BASE CODE GENERATION

Richard E. Williams, Fairfax, Va., assignor, by mesne assignments, to Melpar, Inc., Falls Church, Va., a corporation of Delaware

Filed July 24, 1958, Ser. No. 750,828
22 Claims. (Cl. 340—347)

The present invention relates generally to pulse coding and decoding by means of mixed base techniques, and more particularly to mixed base modulation and demodulation techniques wherein are employed a variety of modulation methods, including pulse amplitude modulation, pulse width modulation, pulse position modulation subcarrier modulation and combinations of these modulations, applied to a single pulse.

In accordance with the present invention, mixed base digital words are employed, wherein each digital word corresponds with a series of digits rooted each in a different base, as distinguished from the conventional digital word wherein all the digits are rooted in the same base system. It may be shown, in such case, that if the roots, bases or moduli of the system are relatively prime, i.e. have no common factor other than one, that a sequence of digital words may be generated which contain no ambiguities over a range of words equal to the product of the moduli. Such words may be generated by simultaneously adding units to each order or line of a word, without carry from one order to another, which leads to techniques for rapid processing in the arithmetic functions, and which requires particularly uncomplicated circuitry. Physical quantities of analogue nature may have their magnitudes converted to mixed base notation, for transmission to remote locations in telemetric systems, the use of mixed base notation presenting for this application advantages over binary, binary-decimal or decimal notation, in many respects. While avoidance of carry in arithmetic computation is one advantage, in computing with mixed base numbers, the use of bases or moduli which are adjacent in value permits the transmission of quantized signals employing similar increments of value in the several orders of a mixed base number. For example, by using moduli 9, 10, 11 each digit of a word varies from an adjacent value by about 10%, and this is true of all the digits of the number. Approximately 1,000 different magntiudes may be transmitted by means of three numbers, each of which may assume approximately ten discrete values, all the values being of the same order of magnitude. It follows that high accuracy telemetric systems may be vastly simplified.

It is thus seen that each number in a mixed base code may be represented as a multi modulo or mixed base word, i.e. each number is represented by a plurality of separate numerals having a separate, relatively prime base or radix. Thus, the rigital number twenty may be represented as a mixed base word having three separate moduli or bases 9, 10, 11 by the separate numerals 2, 0, 9.

In accordance with the present invention, mixed base words are recorded on tape, or are otherwise stored. The stored words may derive from any one of a number of sources, such as computers, transducers, or the like, and represent information. This information is to be transmitted to a remote location, preferably in the form of modulated pulses, and to be demodulated at the remote location or reconverted to mixed base words. Modes of modulation which may be employed include serial pulses, which may be AM, PWM or PPM modulated, or parallel pulses which may be frequency modulated. Additionally, pulses may be utilized each of which is modulated in plural modes, and an exemplary system is described and illustrated employing single pulses each of which is modulated in amplitude, width and frequency, according to

three digits of a mixed base tri-modulo word. Thereby, the possibility exists of transmitting an extremely large number of values by means of a single pulse. For example, a single pulsed carrier having nine possible values of amplitude, ten possible values of width and eleven possible values of carrier frequency, may transmit an item of information, in a fraction of a microsecond, with a resolution of approximately one part in a thousand.

It is, accordingly, a broad object of the present invention to provide systems for converting mixed base words to serial or parallel pulse code groups, wherein the pulses are either AM, PPM or PWM modulated, and to provide demodulators for such systems.

It is another object of the present invention to provide a system for converting a mixed base word to a single pulse having plural characteristics, each characteristic being representative of the value of one digit of the mixed base word.

It is another object of the present invention to provide a system of code conversion, wherein an input code consists of a multi-modulo word, the digits of which exists simultaneously in positional form, and wherein an output code consists of a multi-modulo word the digits of which are generated sequentially as modulations of pulses.

It is still another object of the present invention to provide a system of code conversion, wherein an input code word consists of multiple digits each based on a different modulus, and wherein the output code consists of a single pulse having various of its characteristics representative of different digits of the mixed base word.

It is a more specific object of the invention to provide a system for translating recorded mixed base words to pulsed signals, the pulses of which are modulated to represent the mixed base words.

It is a generic aspect of the invention to provide modulators and demodulators capable of code conversion in mixed base notation.

The above and still further objects, features and advantages of the present invention will become apparent upon consideration of the following detailed description of several specific embodiments thereof, especially when taken in conjunction with the accompanying drawings, wherein:

FIGURE 1 is a conventionalized representation of an indicia bearing tape, and read-out electrodes for the indicia, wherein the indicia are coded in mixed base notation;

FIGURE 2 is a block diagram of a system for converting mixed base code, read-out of the tape of FIGURE 1, to pulse amplitude modulated code;

FIGURE 3 is a representation of a group of amplitude modulated pulses, as generated by the system of FIGURE 2;

FIGURE 4 is a block diagram of a demodulator for the pulse amplitude modulated signals generated by the system of FIGURE 2;

FIGURE 5 is a block diagram of a system for converting mixed coded signals to pulse width modulated signals;

FIGURE 6 is a representation of the pulse shapes of signals generated by the system of FIGURE 5;

FIGURE 7 is a block diagram of a demodulator for demodulating the signals generated by the system of FIGURE 5;

FIGURE 8 is a block diagram of a system for converting mixed base code to pulse position modulated signals;

FIGURE 9 is a representation of the character of the signals generated by the system of FIGURE 8;

FIGURE 10 is a block diagram of a demodulator for signals of the type generated by the system of FIGURE 8;

FIGURE 11 is a block diagram of a system for converting mixed base signals to sub-carrier frequency modulated signals;

FIGURE 12 is a representation of the frequencies of signals generated by the system of FIGURE 11;

FIGURE 13 is a block diagram of one modification of a demodulator capable of demodulating the signals generated by the system of FIGURE 11;

FIGURE 14 is a block diagram of a modification of the system of FIGURE 13;

FIGURE 15 is a block diagram of a system for converting mixed base coded signals to single pulses wherein each pulse has a plurality of characteristics, each representative of a different digit of a mixed base word; and

FIGURE 16 is a block diagram of a demodulator system for the signals generated by the modulator of FIGURE 15.

Referring now more specifically to the accompanying drawings, and particularly to FIGURE 1 thereof, there is illustrated a tape **10** on which is provided mixed base information in the form of indicia located along the length of the tape at positions having significance in mixed base notation. More particularly, the tape **10** may be divided into successive longitudinally spaced imaginary lines shown in FIGURE 1 as lines **11**, **12**, **13**, **14**, **15** and **16**, each line representing a code position. Proceeding from left to right transversely of the tape, four positions are provided, the first of which is utilized for inserting a reset pulse R, located at the line **17** longitudinally of the tape, and the remaining three transverse positions **18**, **19** and **20** being reserved for the different bases, respectively, of mixed base coded words. Assuming use of a 3, 4, 5 code, i.e., a code utilizing a base 3 in the first position, the base 4 in the second position and the base 5 in the third position, five coding positions are required longitudinally of the tape. Indicia are placed on the longitudinal line **18** in coincidence with the transverse lines **11**, **11** and **12**, or **11**, and **12** and **13**, for numerical values 1, 2, 3, respectively, i.e., at line **11** only to represent the value 1, at line **11** and **12** to represent the number 2, to the base 3, or at lines **11**, **12** and **13** if the number 3 is to be represented to the base 3. On the longitudinal line **19** are inserted similarly a number of indicia representative of a mixed base number to the base 4, and on the longitudinal line **20** is inserted a sequence of indicia representative of a number to the base 5. In each case the number of indicia represents the number. Accordingly, the coded tape **10**, as illustrated in FIGURE 1 of the accompanying drawings, represents the numerals 1, 2, 4 to the bases 3, 4, 5, or moduli in mixed base nomenclature.

It will be appreciated that other types of codes may be employed in the present system if desired, and that a wide variety of indicia may be employed, as for example, magnetic indicia, punched holes, conductively coded spots and the like. It will be further appreciated that any desired number of bases may be employed in the system and that the bases 3, 4, 5 are described as employed in the exemplary embodiment of the present invention for the sake of simplicity only.

It is assumed that data to be transmitted has been converted to mixed base code and has been inserted on a tape, such as **10**. The problem posed for solution by the present invention is that of transmitting the information from the tape **10** to a remote location by means of various types of modulation and the demodulation of the transmitted information, at such remote locations. To this end four read-outs A, B, C, D are provided, for read-out of reset pulses and for reading out the indicia at lines **18**, **19**, **20** respectively.

Referring now more particularly to FIGURE 2 of the accompanying drawings, there is illustrated a transmitter for generating pulse amplitude modulated pulses representative of mixed base information. It is assumed that the read-out terminals of the tape read out device of FIGURE 1 are connected, respectively, to the correspondingly lettered terminals of the system of FIGURE 2, i.e., that the reset indicium **17** when sensed will be applied by means of the terminal A of FIGURE 1 to the terminal A of FIGURE 2 and will be applied to reset all the three rings of 3, 4, 5 identified by the reference numerals **30**, **31** and **32**. It is further assumed that the base 3 read-out B, the base 4 read-out C and the base 5 read-out D are, respectively, connected to the ring of 3 read-in terminal B of FIGURE 2, to the ring of 4 read-in terminal B, of FIGURE 2 and to the ring of 5 read-in terminal D of FIGURE 2. It is assumed that the rings initially are set to zero, and are stepped around in response to pulses provided at the read-in terminals B, C and D as the indicia on tape **10** ride under the sensing elements.

In FIGURE 2 the ring of three, **30** is connected at its three output terminals in series with resistances R1, R2, R3, respectively, which may all be equal and are relatively large. Resistance R1 leads through junction **37**, and three resistances **34**, **35** and **36** to ground. The resistances **34**, **35** and **36** may all be equal and may be much smaller than the resistances R1, R2, R3. The resistance R2 proceeds to the junction **38** of resistances **34**, **35** and the resistance R3 to the junction **39** of resistances **35** and **36**. As seen from the terminal **37**, **38** or **39**, the ring of 3 and the very large resistances R1, R2, R3 at the outputs thereof appear as a constant current generator. It follows that a voltage is developed between the terminal **37** and ground which depends upon which one of the junctions **37**, **38**, **39** has current applied thereto from the ring of three, **30**. Moreover, the voltage which will appear at the junction **37** may have one of three quantized values, the smallest of which exists when current is applied to the terminal **39**, the next higher one of which exists when current is applied to the terminal **38**, the highest one of which exists when current is applied to the terminal **37**.

A resistance network generally indicated by the refernece numeral **40**, is employed in conjunction with the ring of four, **31**, and generates one of four quantized values at the junction point **41** in dependence upon the setting of the ring of four, **31**. Additionally, a further resistance network **42** is applied to the output of the ring of five, **32** for the purpose of generating five quantized voltages at output terminal **43**. Since the general philosophy of the networks employed for generating the quantized voltage is the same for each of the ring counters, further explanation of the operation thereof is dispensed with.

It is now clear that quantized values of voltages will appear at the terminals **37**, **41** and **43**. These values persist until the tape reaches its fifth longitudinal position, at which time the maximum possible mixed base read-out has been inserted in the ring counters **30**, **31** and **32**. Upon attaining the sixth position of the tape **10**, a reset pulse is applied to the terminal A. This reset pulse proceeds via a lead **45** to a trigger source **46**, which triggers a first pulse generator **47**. The latter applies a gating pulse to the normally closed gate **48**, and permits voltage from the terminal **37** to proceed to the output terminal **50** of the modulator. Upon termination of the pulse of the first pulse generator **47** and in response to the trailing edge thereof, a trigger pulse is applied via lead **51** to a second pulse generator **52**. The latter applies a gating pulse to open the normally closed gate **53**, transferring voltage from the junction **41** to the output terminal **50**. On termination of the gating pulse generated by the second pulse generator **52** and in response to the trailing edge thereof, a further trigger pulse is applied via lead **54** to a third pulse generator **55**, which supplies a gating pulse to open the normally closed gate **56**, permitting the voltage at the terminal **43** to be applied to the output terminal **50**. Shortly thereafter the reset pulse which had, during the gating operation, been delayed in the delay device **57**, is applied via leads **58**, **59** and **59A** to reset the rings **30**, **31** and **32**, in preparation for insertion of a succeeding set of mixed base numbers from the tape **10**.

At the output terminal, **50**, appears then three sequential pulses having pulse heights which are coded in ac-

cordance with a mixed base code, in accordance with the information inserted into the input terminals B, C, D of ring counters 30, 31 and 32. The typical appearance of a wave form provided at the output terminal 50 is that shown in FIGURE 3 of the accompanying drawings, wherein the dotted lines indicate possible quantized amplitude values and the full lines represent an actual code representation of the number 2, 3, 4 in mixed base notation to the base 3, 4, 5.

The pulses are transmitted in succession, the first pulse 60 being to the base 3, the second pulse 61 being to the base 4, and the third pulse 62 being to the base 5. The total transmission times of the pulses may be extremely short, i.e., burst transmissions may be utilized, and the three pulses taken together represent sixty bits of information in terms of the twelve possible quantized amplitude values of the three pulses taken collectively.

The sequence of amplitude modulated pulses appearing at the terminal 50 may be transmitted to a remote point via a radio link, a wire link, or in another conventional fashion, and may be there detected in conventional fashion, and applied to an input terminal 80 of a demodulator system, illustrated in FIGURE 4 of the accompanying drawings. In the system of FIGURE 4, and connected in parallel to the input terminal 80 are a first pulse extractor 81, a normally closed second pulse gate 82 and a normally closed second pulse gate 83. The first pulse extractor 81 is of conventional character per se, and is a normally open gate circuit which responds to a first of a group of pulses and thereafter cuts itself off for a predetermined period. A typical such device is a mono-stable flip-flop.

In accordance with the present invention, the off-gated period of first pulse extractor 81 is made sufficiently long that a group of two following amplitude modulated pulses may be provided to the terminal 80 while the circuit is gated off. A second pulse gate 82 is normally closed, but is turned on for a short interval encompassing the second of the received pulses, in response to passage of the first pulse by the first pulse extractor 81. Similarly, a third pulse gate 83 is turned on in response to passage of the second of three pulses by the second pulse gate 82. The output of the first pulse extractor 81, the second pulse gate 82, and the third pulse gate 83, are applied respectively to amplitude discriminators 84, 85 and 86. The amplitude discriminator 84 is a modulo 3 discriminator, i.e., it includes three channels for selecting three discrete levels of input signal corresponding with the three levels that may be encountered in the first of the pulses transmitted by the system of FIGURE 2. On a similar basis the amplitude discriminator 85 is modulo 4 and the amplitude discriminator 86 is modulo 5. There are, accordingly, three output terminals 87, for the amplitude discriminator 84, four such terminals 88 for the amplitude discriminator 85, and five such terminals 89 for the amplitude discriminators 86. The output of the system is accordingly a mixed base coded group of signals, employing the bases or moduli 3, 4, 5, i.e., the same bases as were utilized for the input signal.

Referring now more particularly to FIGURE 5 of the accompanying drawings, there is illustrated a system for converting mixed base coded pulses into pulse width modulated pulses. Identical elements of the systems of FIGURES 2 and 5 are identified by the same numerals of reference and description of these elements in connection with the description of the system of FIGURE 5 is accordingly dispensed with. It is assumed that at terminals 41 and 43, respectively, appear voltages having amplitudes representative of the three values of a mixed base number having the bases 3, 4 and 5. In cascade with the terminal 37 is connected a full width normally closed gate 90, which in response to a trigger supplied by a trigger source 91 opens for a predetermined interval longer than the maximum length allocated for the PWM pulse modulo 3, so that a pulse is provided at the output of the full width gate 90 having a predetermined width and an amplitude proportional to the voltage at the terminal 37.

In cascade with the full width gate 90 is provided an integrating circuit 92, shown in simple conventionalized form, as consisting of a series resistance 93 and a shunt capacitor 94. Obviously, more sophisticated types of integrator circuits may be employed, if desired. At the output terminal 95 of the integrator 92 appears a sawtooth voltage which rises at a rate determined by the pulse amplitude of the signal being integrated. The voltage at the terminal 95 is applied to a pulse width generator 96, which generates a pulse only while the voltage at terminal 95 is below some predetermined value. Accordingly, at the output terminal 97 of the pulse width generator 96 appears a pulse having a width which is an inverse function of the height of the pulse provided by the full width gate 90.

The pulse width generator 96 may typically comprise a flip-flop circuit, which is started in response to a trigger pulse supplied by trigger source 91 via lead 98 and which is terminated when the amplitude of the integrator voltage at terminal 95 reaches a predetermined value. However, other types of devices for converting pulse amplitude to pulse width may be employed in the practice of the present invention, and I do not desire to be limited to any specific type of pulse height to pulse width conversion device.

The trailing edge of the full width gate 90 may, with suitable delay, be applied to a lead 99, which then acts to trigger a full width gate 100, which is in cascade with the terminal 41 pertaining to the modulus 4. In cascade with the full width gate 100 is an integrator circuit 101 and a pulse width generator 102, the latter being connected via lead 103 to the output lead 97. There is, accordingly, in cascade with the terminal 41 a voltage to pulse width conversion circuit which operates precisely as does the circuit pertaining to the modulus 3 but which derives its voltage amplitude at the terminal 41. The trailing edge of the pulse provided by the full width gate 100 may be applied to a lead 104, and thence is applied to the full width gate 106, and the pulse width generator 107, which are in cascade with the terminal 43 pertaining to the modulus 5. The output of the pulse width generator 107 is applied via lead 103 to the output lead 97.

In operation then the voltages at the terminals 37, 41 and 43 are sampled in time sequence, and caused to generate in the full width gates 90, 100 and 106, respectively, pulses having predetermined width which are all equal, but having amplitudes which represent the amplitudes of the voltages at the terminals 37, 41 and 43. The amplitude modulated pulses of uniform width so generated are integrated in conventional integrators, one pertaining to each of the modular channels. Concurrently with initiation of operation of each full width gate, as 90, 100 and 106 a pulse of constant amplitude is initiated in each of the channels at the pulse width generators 96, 102 and 107, so that these pulses are generated in sequence. Each of these pulses is, however, cut off upon attainment in the integrators 92, 101, 103, respectively, of predetermined amplitudes of integrated signals, times of attainment of which are direct functions of the amplitudes of the pulses applied to the integrators. Accordingly, the widths of the ultimately generated pulses, at output lead 97 are inversely proportional to the amplitudes of the voltages at junctions 37, 41, 43.

The appearance of the transmitted pulses, 110, 111, 112 is illustrated in FIGURE 6, wherein is shown in full lines a sequence of three pulses representative of the number 2, 2, 2, in mixed base code modulo 3, 4, 5.

Proceeding now to FIGURE 7 of the accompanying drawings, there is illustrated a pulse width modulation

demodulator for converting the pulse width modulated signals provided by the system of FIGURE 5 into mixed base words. For the purpose of this discussion it is assumed that the pulse width coded group consisting of pulses 110, 111, and 112 is applied to an input terminal 80, in the form of D.C. pulses. This implies that if transmission was by radio, that a suitable carrier receiver and detector exists antecedent to the terminal 80.

The pulse train applied to the terminal 80 is fed to three parallel channels comprising a first pulse extractor 81, a second pulse gate 82 and a third pulse gate 83, which correspond with the correspondingly numbered elements of the system of FIGURE 4. Thereby, the first pulse 110 is channeled to an integrator 115, the second pulse 111 is channeled to an integrator 116 and the third pulse 112 is channeled to an integrator 117. Integrators 115, 116 and 117 are provided with output terminals 118, 119 and 120 and serve respectively to convert pulses supplied thereto to steady voltages having amplitudes proportional to the pulse widths. The voltages available at the terminals 118, 119 and 120 are applied, respectively, to amplitude discriminators 84, 85 and 86 which convert these amplitudes to mixed base coded words by selecting appropriate ones of the terminals 87, 88 and 89. For the exemplary transmitted code word 2, 2, 2 for example, the second terminal of terminals 87, the second terminal of terminal 88 and the second terminal of terminal 89 would be energized.

The third pulse gate 83 supplies a control pulse via a lead 122 to a discharge and reset pulse generator 123, at the termination of the last pulse 112, and the reset pulse is applied via lead 124 to the output terminals 118, 119 and 120 of the three integrators 115, 116 and 117, to discharge the condensers thereof in preparation for a succeeding pulse group.

Reference is now made to FIGURE 8 of the accompanying drawings, wherein is illustrated a system for converting a mixed base coded group of input signals, such as are provided by the system of FIGURE 1, to a pulse position modulated group of pulses having mixed base significance. It is assumed, to simplify the explanation, that the rings of three, four and five, respectively, have been set by incoming pulses deriving from tape 10 (FIGURE 1) to positions corresponding with the values of the incoming pulse groups, in a manner which has been hereinabove explained in detail.

In consequence, and considering particularly the ring of three, 30, one of the three output leads 150, 151 and 152 is energized and the remainder are unenergized. A sync pulse generator 153 is provided, which periodically supplies a sync pulse, for initiating read-out of the ring counters 30, 31 and 32. The sync pulse generator 153 supplies a sync pulse, illustrated at 154 of FIGURE 9, to the ring of three, 30, via a lead 156, and simultaneously supplies that sync pulse to an output lead 155. The read-out pulse supplied to the ring of three, 30, via the lead 156, effects read-out of the ring of three, 30, by applying a responsive pulse selectively to one of the leads 150, 151 and 152, which correspond with the count set into the counter. If the lead 150 is energized, an output pulse proceeds via a delay device 160 to the output lead 155. The delay device 160 possesses a delay time T appropriate to one time channel of the system. If the lead 151 is energized, the pulse proceeds via the delay device 161 and 160 in cascade to the output lead 155. If the output lead 152 is energized, on the other hand, a pulse proceeds via delay devices 162, 161 and 160 in cascade, to the output lead 155. It follows that an information pulse will be applied to the lead 155 with a delay which corresponds with that one of the leads 150, 151 and 152 which have been energized, and correspondingly with the setting of the ring of three, 30. The ring of four, 31, includes four output leads 167, 168, 169 and 170 which are connected to a cascaded set of four delay devices 171, each of which has a delay time T. The delay devices 171 are connected in cascade with the delay device 162. Accordingly, the ring of four, 31, in response to a synchronizing pulse supplied over the lead 165 simultaneously with a syinchronizing pulse supplied over the lead 156 to the ring of three, 30, effects a read-out of the ring of four, 31. This pulse reaches the input of the delay device 162 after a delay corresponding with the numerical value of the setting of the ring of four counter 31. By a similar technique, involving a cascaded set of delay devices 172, the ring of five, 32, if read-out. There are, in toto, twelve delay devices, each having the same delay time T, and which establish twelve time positions following the synchronizing pulse 154. One of the first three of these time positions (FIGURE 9) is occupied by a pulse according to the setting to the ring of three, 30. One of the next four positions is occupied as a function of the setting of the ring of four, 31 and one of the remaining five positions is occupied according to the setting of the ring of five, 32. In FIGURE 9 is illustrated in dotted outline the possible pulse positions following the synchronizing pulse 154, and in full lines the occupied positions for a mixed base word 2, 3, 4.

The pulses provided at the output lead 155 are transmitted to a remote point by means of a radio link or in some other convenient mode, where they are applied as D.C. pulses to an input terminal 200, of a PPM demodulator (FIGURE 10). This implies that the necessary demodulation system or receiver device is provided antecedant to the terminal 200. The train of pulses applied to the terminal 200 proceed to a sync pulse extractor 201, which provides an output pulse in response to the sync pulse 154, selecting the latter on the basis of its amplitude. The output pulse proceeds to a cascaded set of twelve delay lines, 202. The sync pulse extractor 201 channels the remaining pulses of the pulse train, excluding the sync pulse, to a common lead 203, whence these pulses are applied in parallel via leads 204, 205 and 206 to a set of three coincidence gates 207, 208 and 209. The coincidence gates 207 comprise three gates, while the coincidence gates 208 and 209 comprise four and five gates, respectively, these gates being connected jointly to the leads 204, 205 and 206 for each set, and being connected individually via leads such as 210 to the outputs of the several delay lines 202. It follows that one gate of each of sets 207, 208, 209 will be selected, and will energize the corresponding ones of the output terminals 211 and the selection will occur in accordance with the time positions of the received pulse train, since the delay devices 202 have delay times T which are precisely the same as the delay times T utilized for the cascaded delay devices of FIGURE 8.

In the system of FIGURE 11 of the accompanying drawings, three frequency modulated sub-carriers are employed to represent the values of three numerals of a mixed base word. Mixed base signals are initially translated or converted into amplitudes of voltages, as in the system of FIGURE 2, of the accompanying drawings, these voltages appearing at terminals 37, 41 and 43. The voltages there appearing are applied to a set of frequency modulators 250, 251 and 252, respectively, which in turn set the frequencies of sub-carrier oscillators 253, 254 and 255. Accordingly, the sub-carrier oscillator 253 may provide any one of three values, the sub-carrier oscillator 254 any one of four values, and the sub-carrier oscillator 255 any one of five values, since the moduli of the system are 3, 4, 5.

Reference is made to FIGURE 12 of the accompanying drawings, which provides a plot of frequencies of sub-carriers with respect to a main carrier frequency on the assumption that the outputs of the sub-carrier oscillators 253, 254, 255 are applied to a common output lead 256 in which turn amplitude modulates an R.F. carrier. In FIGURE 11 the carrier is assumed to be 257 and the sub-carrier frequencies for code value of 2, 3, 4 are shown at 258, 259 and 260, respectively, the dotted ordinates in

FIGURE 11 representing possible positions for sub-carrier frequencies.

Two different systems are provided for demodulating the signals of the type transmitted by the system of FIGURE 11. In one of these systems the radio frequency carrier is detected in conventional fashion, so that the sub-carriers may be removed and applied to an input terminal 270 of FIGURE 13. Terminal 270 is connected in parallel to three sets of filters, one of which consists of three filters, each tuned to a different one of the sub-carrier frequencies assigned to the sub-carrier oscillator 253, of FIGURE 10, the other set consisting of four parallel filters 274, 275, 276 and 277, which are tuned, respectively, to accept selectively the sub-carrier oscillator frequencies available to the sub-carrier oscillator 254, the remaining group of filters 278 to 282, inclusive, respectively, being each tuned to a different one of the frequencies available to the sub-carrier oscillator 255. The signal outputs of the filters 271, 273, inclusive, are used to set a ring of three counter 283 to a value corresponding with the filter which is energized. Similarly, the set of filters 274–277, inclusive are used to establish a setting for a ring of four counter, 284, in correspondence with the filter which is selectively energized, while the set of filters 278–282, inclusive, establishes a setting for a ring of five counter 285. Accordingly, the output terminals 286, 287 and 288 of the several rings are energized in mixed base notation in accordance with the transmitted signal.

In accordance with a modification of the system of FIGURE 13, illustrated at FIGURE 14 of the accompanying drawings, instead of utilizing discrete filters for detecting the several sub-carrier frequencies, frequency discriminators are employed. The outputs of these are then selected by means of amplitude discriminators. To this end, the input terminal 270 supplies signal to three frequency discriminators 300, 301, and 302, in parallel. The discriminator 300 provides one of three amplitudes of output signal according to which of the three modulo three sub-carriers are transmitted. Likewise, the frequency discriminator 301 provides four discrete levels of D.C. output, and the frequency discriminator 302 provides five discrete levels of output. Accordingly, at the output terminals 303, 304 and 305 of the frequency discriminators 300, 301 and 302 appear three D.C. levels representative of the three sub-carrier frequencies. These D.C. levels are separated by means of amplitude discriminators 306, 307 and 308, as in FIGURE 4, and accordingly, one output lead is selected from each of the sets of leads 286, 287, 288.

While a mixed base system employing moduli 3, 4, 5 has been described for exemplification, in the description of the present system, which provides a resolution of one part in sixty, resolutions of this order can be more easily obtained through simple analogue transmission methods. The significant advantages of mixed base techniques become more evident as the number of moduli, or the modulo values themselves, are increased. For example, a 5, 6, 7 combination will yield data transmission accuracies in the order of 0.5% whereas no circuit is required to read a parameter to an accuracy of better than 14%; and no more than 18 parallel circuits are involved. The advantages of flash communications are noteworthy and this type of communication is particularly advantageous in connection with mixed base techniques. For example, a sequential tri-modulo mixed base group of pulses, and where parallel transmission occurs, such as in the sub-carrier frequency embodiments of FIGURES 11–14, inclusive, a total of .25 micro-second may be required to transmit one word.

Insofar as the system of FIGURE 15 corresponds with the system of FIGURE 3 of the accompanying drawings, identical elements have been identified by the same numerals of reference, and their description is dispensed with. There is, accordingly, in the system of FIGURE 15, available three voltages, at the terminals 37, 41 and 43, these voltages being quantized and having values depending upon the mixed base code read-out from the tape of the read-out device of FIGURE 1. After the voltages have been set up at the terminal 37, 41 and 43, a reset pulse is read-out from the tape 10, which is applied to the terminal A and therefrom is applied via a lead 320 to a pulse source 321. The pulse source 321 provides a single pulse to a pulse amplitude modulator 322 and to a pulse width modulator 323. The pulse width modulator 323 generates a pulse having one of four widths, selected in accordance with the setting of the ring of four, 31, and applies this pulse to an amplifier 324. The latter is controllable in respect to the amplitude of its output in response to an amplitude control voltage, which in fact constitutes the output pulse from the pulse amplitude modulator 322 and is applied to the amplifier 324 by means of a lead 325. Accordingly, an output lead 326, deriving from the amplifier 324, carries a single pulse the width of which represents the setting of the ring of four, 31, and the amplitude of which represents the setting of the ring of three, 30. The voltage available at the terminal 43, which represents the setting of the ring of five, 32, is applied to a frequency modulator 327, setting the frequency of the latter at one of five possible values. The output of the frequency modulator 327 is accordingly a CW signal having one of the five permissible frequencies, and is applied to an amplitude modulator 328 which is pulsed by the signal arriving over the lead 326. The output signal derivable from the amplitude modulator 328 is accordingly a pulse carrier having a frequency which is a function of the setting of the ring of five, 32, the pulse having a width representative of the setting of the ring of four, 31, and the height of the pulse being representative of the setting of the ring of three, 30. The pulse so generated is applied to an R.F. modulator, 329, which modulates an extremely high frequency carrier, and transmits same to a remote location over an antenna 330. The total duration of the pulse generated may be considerably less than one-microsecond, i.e., burst transmission techniques may be employed.

Following transmission of the burst, the reset pulse applied to the terminal A arrives at the rings of 3, 4, and 5 identified by the reference numerals 30, 31 and 32, via a delay device 57 and the leads 331, 332 and 333 respectively, and serves to reset these counters in preparation for a following read-out from tape 10. The system of FIGURE 16 represents in block diagram a demodulator for the signals generated by the system of FIGURE 15. In the system of FIGURE 16 is provided an antenna 341 which is coupled with an R.F. detector 342. At the output terminal 343 of the latter is provided a sub-carrier signal in the form of an amplitude modulated and width modulated pulse carrier, such as is provided by the amplitude modulator 328 of FIGURE 15. This pulse is applied via a lead 244 to a frequency discriminator 345, at the output of which appear one of five D.C. levels in correspondence with that one of the five available sub-carrier frequencies generated by the frequency modulator 327. These are amplitude discriminated in an amplitude discriminator 346 and applied selctively to the leads 347, that one of the leads 347 being energized which represents the amplitude of the D.C. output of the frequency discriminator 349. The signal appearing at the lead 359 is a pulse sub-carrier. It is detected in two separated channels. In one of these channels is provided a sub-carrier demodulator or detector 350 which provides at its output a D.C. pulse having the amplitude of the pulse provide by the pulse amplitude modulator 322. This pulse is applied to an amplitude discriminator 351, which selects one of the output leads 352, according to the amplitude of the input pulse.

In a second channel is provided a further sub-carrier detector 354, the output of which is applied to a pulse type limiter 355, at the output of which appears a pulse which is of uniform height, regardless of the amplitude of the

input pulse, but which has a width corresponding with the width of the pulse generated by the pulse width modulator 323 of FIGURE 15. The pulse width modulated pulse provided by the pulse height limiter of 355 is applied to a pulse width to pulse height converter 356, and the output of the latter is applied to an amplitude discriminator 357 which selects one of four terminals 358, according to the amplitude of the input pulse.

At the output terminals 352, 358 and 347 corresponding with the mixed base moduli 3, 4 and 5 there is, accordingly, provided signals representative of the settings of the ring counters 30, 31 and 32, which in turn represent indicia in mixed base notation read-out of the storage tap 10 of FIGURE 1.

It will be clear that the system of FIGURES 15 and 16 may be modified in respect to the moduli employed, in any one of the channels. For a 3, 4, 5 base system for example, frequency may represent the modulus 3, pulse width may represent the modulus 5 and pulse height may represent the modulus 4. It will be further clear that, in place of pulse width, pulse position may be employed as one of the modulating devices, i.e., that three mixed base digits may be transmitted to a remote location and there be demodulated, by means of a system in which one digit is transmitted in the form of pulse position, one digit in the form of pulse height, and one digit in the form of pulse carrier frequency.

While I have described and illustrated various specific embodiments of my invention, it will be clear that variations of the details of construction which are specifically illustrated and described may be resorted to without departing from the true spirit and scope of the invention as defined in the appended claims.

What is claimed is:

1. In combination, a plurality of ring counters each having a different base, means for setting each of said ring counters to a number, the array of numbers corresponding with the settings of said ring counters representing a mixed base word, a separate network in cascade with each of said counters for converting the settings of said counters to signal amplitudes representative of the settings of said counters, and means for converting said signal amplitudes to pulse coded signals.

2. The combination according to claim 1, wherein said means for converting includes means for converting said signal amplitudes to pulse amplitude modulated signals.

3. The combination according to claim 1, wherein said means for converting includes means for converting said signal amplitudes to pulse width modulated signals.

4. The combination according to claim 1, wherein said means for converting includes means for converting said signal amplitudes to pulse frequency modulated signals.

5. In combination, a first ring counter modulo n, a second ring counter modulo m, where m and n are relatively prime, means for inserting into said first and second ring counters the elements of a two element word in a mixed base code based on moduli m and n, said first ring counter having m output terminals corresponding respectively with m counters, said second ring counter having n output terminals corresponding respectively with n counts, a separate relatively high resistance in cascade with each of said terminals of said first counter and of said second counter, m relatively small resistances joining said high resistances operatively associated with said first counter to each other and to a point of reference potential and so arranged that a voltage is developed across all said relatively small resistances which represents the count of said first counter, n relatively small resistances joining said high resistances operatively associated with said second counter and so arranged that a voltage is developed across all said last named small resistances which represents the count of said second counter.

6. In combination, a first ring counter having a base modulo m, a second ring counter having a base modulo n, where m and n are relatively prime, first network means connected to said first ring counter for deriving therefrom a voltage having m discrete possible values representative of and responsive to the count of said first ring counter, second network means connected to said second ring counter for deriving therefrom a voltage having n discrete possible values representative of and responsive to the count of said second ring counter.

7. The combination according to claim 6 wherein is further provided means for reading out said voltages in sequence.

8. The combination according to claim 6 wherein is further provided means for translating each of said voltages into a pulse of width representative of one of said voltages.

9. The combination according to claim 6 wherein is further provided means for translating each of said voltages into a pulse having a position representative of amplitude of one of said voltages.

10. The combination according to claim 6 wherein is further provided means for translating each of said voltages into a signal of frequency representative of amplitude of one of said voltages.

11. In a mixed base system of telemetering, a plurality of ring counters having maximum counts which are relatively prime, means for converting the instantaneous counts of said ring counters into voltages having amplitude values representative of said instantaneous counts of said ring counters, means for converting said voltages to pulses, and means for transmitting said pulses to a remote point.

12. In a mixed base system of telemetering, a plurality of ring counters having maximum counts which are relatively prime, means for converting the instantaneous counts of said ring counters into signals having amplitudes representative of said instantaneous counts, and means for converting said signals for each instantaneous count to a pulse having a first pulse characteristic representative of the instantaneous count of one of said ring counters, and having a further characteristic representative of the instantaneous count of another of said counters.

13. The combination according to claim 12 wherein is further provided means for transmitting said pulse to a remote location, and means for receiving said pulse at said remote location and there decoding said pulse to recover the counts of said ring counters.

14. The combination according to claim 8 wherein said means for converting includes means for sequentially converting said signal amplitudes to pulse coded signals.

15. A system for transmitting and decoding information represented in mixed base notation, said notation including N different moduli, where N is any integer greater than one, said moduli being relatively prime numbers, comprising a first set of N rings, each having a different maximum count, said maximum counts being respectively equal to said moduli, means responsive to said information for loading each ring of said first set to a count representing said information, said information representing count being any number between zero and one less than the maximum count in the respective modulus, means deriving a separate output from each count position of each ring of said first set, means responsive to the outputs of the count loaded into said first set of rings for transmitting a group of pulse coded signals to a remote location, said group of pulse coded signals including information regarding the count of each modulus, means at the remote station for receiving and decoding said group of pulse coded signals, said last named means comprising a second set of N rings each having a different maximum count respectively equal to said moduli, and means responsive to the received group of pulse coded signals for loading each ring of the second set to a count representing the information in the received group of pulse coded signals, said last named means including means for feeding information regard-

ing the kth modulus to the ring of the second set for the kth modulus, where k is every one of the N moduli.

16. The system of claim 15 wherein said means for transmitting includes means for deriving amplitude modulated pulses.

17. The system of claim 15 wherein said means for transmitting includes means for deriving width modulated pulses.

18. The system of claim 15 wherein said means for transmitting includes means for deriving position modulated pulses.

19. The system of claim 15 wherein said means for transmitting includes means for deriving frequency modulated pulses.

20. The system of claim 15 wherein $N=3$, and said means for transmitting includes means for deriving a single pulse for each mixed base word, said last named means including means for amplitude modulating said single pulse in response to the count of one of the rings of said first set, means for pulse width modulating said single pulse in response to the count of another ring of said first set, and means for frequency modulating the carrier of said pulse in response to the count of still another ring of said first set.

21. The system of claim 15 wherein said means for transmitting includes means responsive to the count of one ring of said first set for frequency modulating said group of pulse coded signals, and means responsive to the count of another ring of said first set for further modulating said group of pulse coded signals.

22. A system for transmitting information represented

in mixed base notation, said notation including N different moduli, where N is any integer greater than one, said moduli being relatively prime numbers, comprising N rings, each having a different maximum count, said maximum counts being respectively equal to said moduli, means responsive to said information for loading each ring to a count representing said information, said information representing count being any number between zero and one less than the maximum count in the respective modulus, means deriving a separate output from each count position of each ring and means responsive to the outputs of and the count loaded into said rings for transmitting a group of pulse coded signals to a remote location, said group of pulse coded signals including information regarding the count of each modulus.

References Cited in the file of this patent

UNITED STATES PATENTS

2,275,017	McNaney	Mar. 3, 1942
2,756,274	Stenning	July 24, 1956
2,772,399	Jacobsen	Nov. 27, 1956
2,796,602	Hess et al.	June 18, 1957
2,810,518	Dillon	Oct. 22, 1957
2,852,745	Kohs	Sept. 16, 1958
2,964,241	Rosenberg et al.	Dec. 13, 1960
2,997,541	Grottrup	Aug. 22, 1961
3,023,277	Mathews	Feb. 27, 1962

OTHER REFERENCES

Murphey: "Basics of Digital Computers," vol. 1, copyright June 1958, p. 27.