GENERAL RADIO COMPANY

engineering department

INSTRUMENT NOTES

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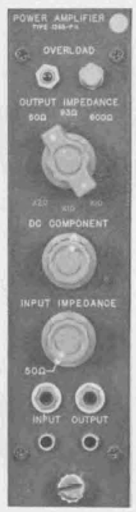
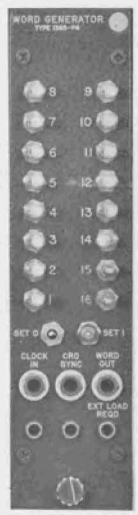
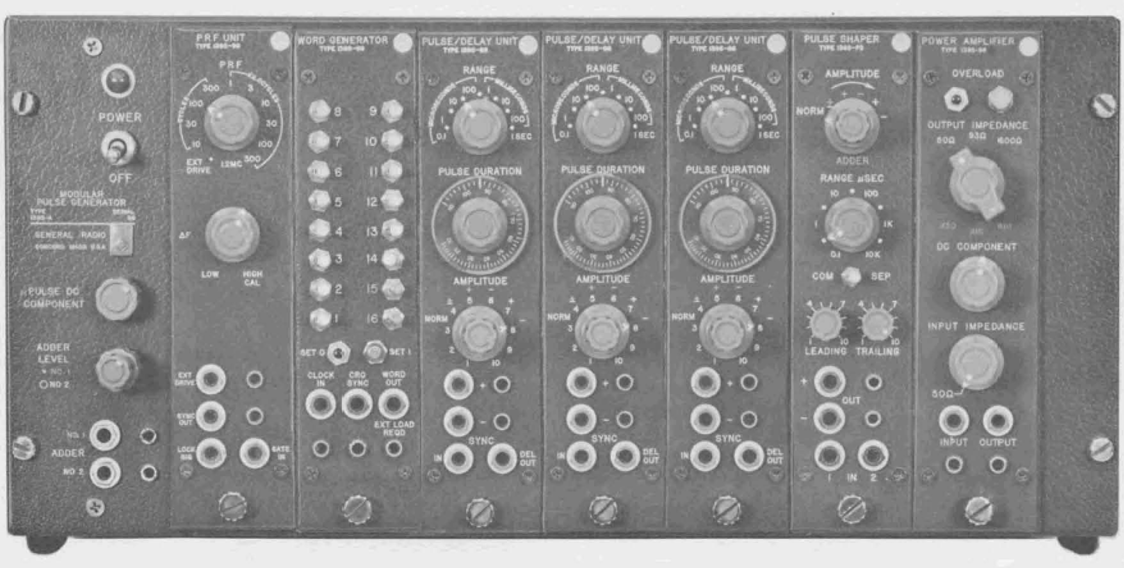
GENERATION AND DETECTION OF MODULATED PULSES







GENERATION AND DETECTION OF MODULATED PULSES

1 INTRODUCTION

The purpose of this application note is to show how various types of pulse modulation can be generated and detected by means of modules of the GR 1395 Modular Pulse Generator family. Certain simple modifications must be made in one module, the Type 1395-P2 Pulse/Delay Unit. A low-pass audio filter is also required.

It is assumed that the reader already has some familiarity with pulse-modulation principles. However, for those getting into pulse modulation work for the first time, an appendix summarizes the types of modulation.

2 SOME GENERAL RULES

Pulse modulation (except PCM, which is a special case) requires that certain simple rules be followed in the choice of pulse repetition frequencies. If the highest audio frequency of interest is f_{max}, then the pulse repetition frequency (prf) must be at least $2f_{max}$. If by any mischance a frequency f greater than f_{max} is used for modulation, a "foldover" effect takes place so that the output frequency is $f_{out} = 2f_{max} - f$. For example, a pulse-modulation system uses a prf of 6 kc/s in anticipation of modulation frequencies in the speech band from 300 c/s to 3 kc/s. Thus, $f_{max} = 3$ kc/s. If a modulating frequency of 4 kc/s is used, the output of a detector will be 2 kc/s.

Distortion occurs if any attempt is made to exceed the natural limitations of the pulses themselves. For example, in a PDM system, suppose the nominal duration of a pulse is 3 microseconds. The duration could actually be between 0 and 6 microseconds in response to modulation. An excessively strong audio signal might drive the duration to 7 microseconds, but it cannot become shorter than 0. The result, after demodulation, would be a severely clipped waveform. Likewise, a PAM pulse usually could not be made smaller in amplitude than 0 volts, although there is nothing inherent in the design of a PAM system that would disallow polarity reversal.

3 GENERATION OF PDM

Pulse-duration modulation (sometimes called pulse-width modulation) is discussed first in this application note because it is easy to produce, and it is a starting point for producing PPM.

Equipment necessary to produce PDM consists of one each of the following:

1. Type 1395-A Modular Pulse Generator (Main Frame)
2. Type 1395-P1 PRF Unit
3. Type 1395-P2 Pulse/Delay Unit
4. An audio-frequency transformer, such as the General Radio Type 941-A
5. An audio-frequency oscillator, such as the General Radio Type 1210-C or Type 1310-A.

Since the Type 1395-A Modular Pulse Generator is not designed primarily for pulse modulation, a simple modification is required. This consists of arrangements for inserting the audio signal in series with the 680-ohm resistor, R224. Figure 1 shows how this resistor can be removed from the PULSE DURATION control potentiometer, R225, and, while left soldered to the switch, can be pushed back away from possible contact with any other components. One audio lead is then connected to the loose end of R224, the other to the solder lug on the back of the PULSE DURATION control. The interconnections between the Pulse/Delay Unit and other equipment are also included in Figure 1. The modules, of course, must be inserted into the main frame after the

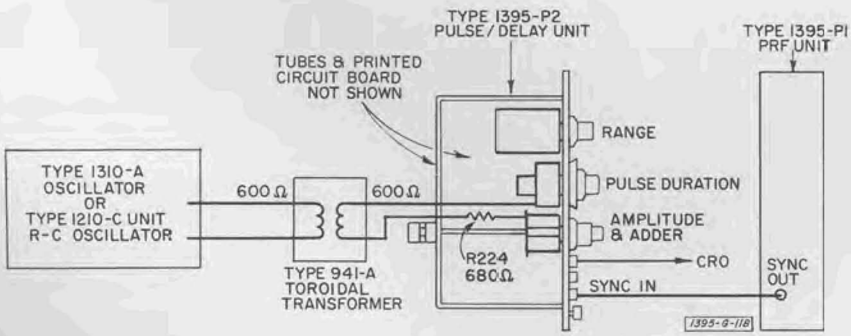


Figure 1.
Connections to a Type 1395-P2 Pulse/Delay Unit to generate PDM.

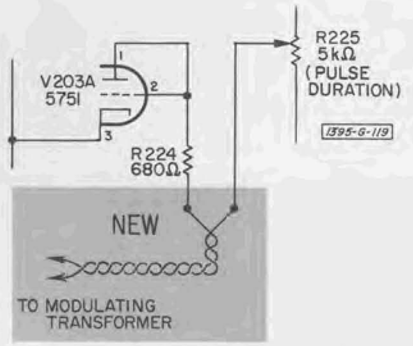


Figure 2. Modification of Type 1395-P2 circuit to insert PDM modulating signal.

modification involving R224 is made. Figure 2 shows the alterations in the Type 1395-P2 circuit diagram after provision for the audio-signal injection.

Now suppose we get down to the actual procedure. Let the audio frequency band be the voice range, with the highest frequency of interest 3 kc/s. Then the pulse repetition frequency must be at least 6 kc/s. For good measure, call it 8 kc/s. With pulses at an 8-kc prf, the spacing between leading edges will be 125 microseconds. Therefore, reasonably long pulses can be used. Say, for example, you select pulses nominally of 60-microsecond duration and allow modulation to swing them from 40- to 80-microsecond duration. Insert a Type 1395-P1 PRF Unit and a modified Type 1395-P2 Pulse/Delay Unit into the Type 1395-A main frame. The transformer leads can be run into the module through one of the two grounding jacks. Set the PRF control to 10 kc/s, and gradually back off (i.e., turn counterclockwise starting from the CALIBRATED point) the vernier ΔF control until the spacing between leading edges of the Type 1395-P2 output pulses is 125 microseconds as seen on an oscilloscope.

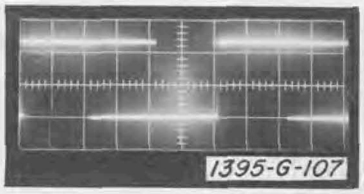


Figure 3. Duration-modulated pulses. Modulation is ± 20 μs superimposed on a nominal duration of 60 μs. PRF = 8 kc/s. Scale: horizontal, 20 μs/major division; vertical, 10 V/major division.

Turn the output control of the Type 1210 RC Oscillator to -50 dB, set the output switch to 0-7 V (in order to have a 600-ohm output impedance), and set the oscillator to any frequency in the 200-2000-c/s range.

Examine the output pulses from the Type 1395-P2 Pulse/Delay Unit. Set the RANGE switch to 10 – 100 microseconds, and, while watching the oscilloscope, adjust the PULSE DURATION control until the time from leading to trailing edge is 60 microseconds. Note that the calibration is thrown off somewhat when the transformer is inserted in series with R224. Now increase the output from the oscillator until the trailing edge of the output pulse changes from a single line to a fuzzy stripe. Continue increasing the gain until the stripe widens to a band starting 40 microseconds after the leading edge and ending 80 microseconds after the leading edge. An actual photograph of a PDM pulse meeting these specifications is shown in Figure 3. Because the trailing edge does not repeat its position from one pulse to the next, there is not sufficient energy delivered to the oscilloscope phosphor to show the band clearly. However, its existence can be inferred from the overlapping of the tops and bottoms of the pulses along their right-hand sides. Incidentally, the trailing-edge band is very easy to see with the eye.

4 GENERATION OF PPM

Pulse-position modulation (PPM) is very easy to produce with the Type 1395-A Modular Pulse Generator. Simply generate a PDM pulse as described in Part 3 of this note. Then connect the DEL OUT terminal of the Pulse/Delay to the SYNC IN terminal of another Type 1395-P2 Pulse/Delay Unit.

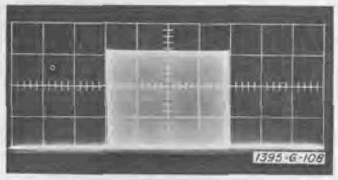


Figure 4. Position-modulated pulses at DEL OUT jack of a Pulse/Delay Unit. Scale: horizontal, 20 μs/major division; vertical, not calibrated, but about 3 V/major division.

The trailing edge of the PDM pulse generates a variable-position pulse at the DEL OUT terminal, and this pulse serves as a variable-time trigger to initiate pulses in the second Type 1395-P2 Pulse/Delay Unit. Figure 4 shows the pulses at the DEL OUT jack, although they appear as a blurred block of light because of the position modulation. In Figure 5 the position-modulated pulse from the second Pulse/Delay Unit is shown. Both photographs were taken under the same conditions as in Part 3: the sampling frequency was 8 kc/s with peak-to-peak modulation of 40 microseconds.

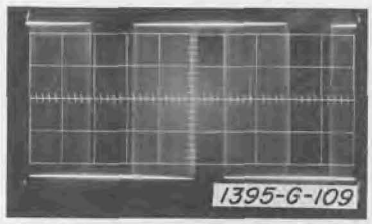


Figure 5. A pulse about 55 μs in duration with ± 20 μs pulse-position modulation. Scale: horizontal, 20 μs/major division; vertical, not calibrated, but about 4 V/major division.

A different method of generating PDM and PPM is described in the instruction book for the Type 1395-P3 Pulse Shaper. This method causes the time at which a triggering level is reached to be dependent on an audio signal added to a triangular waveform. No modification of standard modules is required in this case.

5 GENERATION OF PAM

The Type 1395-P2 Pulse/Delay Unit is designed to operate as a current source from the standpoint of resistors R233A and R233B. Furthermore, approximately the correct current must flow in resistors R238 and R241 for

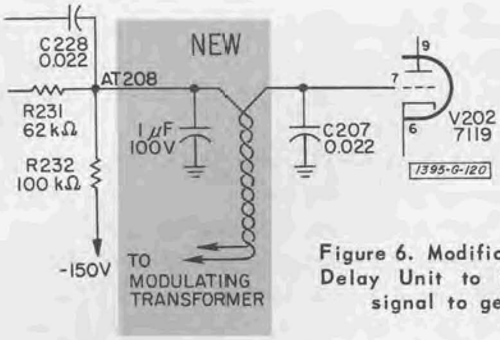


Figure 6. Modification of a Pulse/Delay Unit to insert modulating signal to generate PAM.

proper operation. In order to achieve PAM, the output current must be varied, and this requirement conflicts with the need for a specific current in the flip-flops. Therefore, the degree of PAM that can be produced with a Type 1395-P2 unit is small. However, enough modulation is possible to show the principle.

To generate PAM, connect the secondary of the modulating transformer in series with the lead from anchor terminal AT208 on the etched-circuit board to C207 and pin 7 of the two output tubes. (This lead actually makes contact with the tubes at pin 7 of V202.) The revision of the circuit is shown in Figure 6. For a given amount of impressed audio voltage, the amount of modulation will be increased by addition of a 1-μF capacitor as shown. However, this capacitor is not essential.

It is not possible, with the Type 1395-P2 connected as shown, to obtain amplitude modulation on the positive portion of a pulse. A pulse goes more positive in potential whenever a tube is turned *off*. Therefore, the positive voltage is clamped at the potential set by the PULSE DC COMPONENT control on the Type 1395-A main frame.

Figure 7 illustrates the amplitude modulation obtainable from the circuit of Figure 6. The presence of modulation is evidenced by the thickening at the bottom edge of the pulse. In Figure 8, the mode of oscilloscope synchronization has been changed to show the amplitude modulation on the pulses by another method. Here the presence of PAM is clearly evident as an envelope on the bottom edge of the pulse train.

6 SIMULATING PCM

As stated earlier in this note, true PCM is a relatively difficult signal to generate and requires special encoders or analog-to-digital converters. Simulated PCM, on the other hand, is easily produced with the General Radio Type 1395-P6 Word Generator. This generator produces a repetitive pattern of ones and zeros, depending on the settings of front-panel switches. This pattern is recognized as a binary code by equipment designed to work from such signals and serves as a test signal whose nature one can quickly alter by flipping switches.

Figure 9 shows the method of interconnecting Type 1395 modules to produce a binary word with the Type 1395-P6 Word Generator. In Figure 10, a sample pattern is shown. This is 0010001110001011. For generating words longer than 16 bits, more than one Type 1395-P6 Word Generator can be cascaded, giving at maximum a capacity of 112 bits. Directions for this interconnection are found in the instruction book for the Type 1395-P6 module.

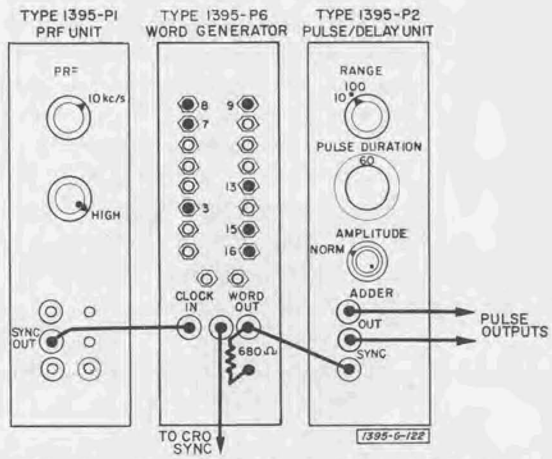


Figure 9. Generation of a synthetic PCM signal.

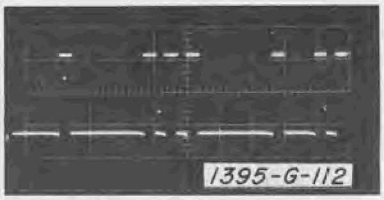
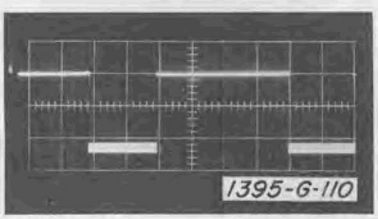


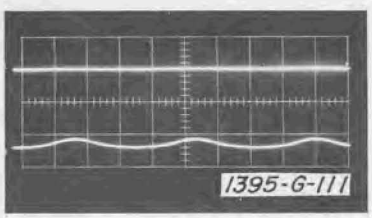
Figure 10. A sample PCM train. Repetition rate of entire train is 1600 μs, corresponding to a time/bit of 100 μs (i.e., bit rate = 10 kc/s). Scale: horizontal, 160 μs/major division; vertical, 10 V/major division. Pattern is 0010001110001011.

7 DETECTING PAM AND PDM

Pulse-amplitude modulation and pulse-duration modulation are detected merely by the passing of the signal through a low-pass filter. The cutoff frequency of this filter should be one half the pulse repetition frequency, or preferably a bit lower. From another viewpoint, the bandwidth of the filter must be from dc to the highest modulating frequency of interest.



(Left) Figure 7. Pulse-amplitude modulation of a negative pulse. PRF =8 kc/s, pulse duration =40 μs. Scale: horizontal, 20 μs/major division; vertical, 10 V/major division. Modulation frequency, about 250 c/s. Oscillogram taken at −OUT terminal of Type 1395-P2 module. (Right) Figure 8. Pulse train of Figure 7, but with oscilloscope synchronized to modulating signal so that amplitude modulation on pulses is clearly visible on envelope on bottom. Scale: horizontal, 160 μs/major division; vertical, 10 V/major division.



That a filter is a sufficient demodulator is more or less intuitively clear if one thinks about the modulation process. In PAM, the amplitude, and therefore the energy, of the pulses will wax and wane through the audio cycle. A component of audio energy is actually stacked on top of the pulses, as it were. All that is necessary to get this audio back is to throw away the high-frequency components represented by the leading and trailing edges of the pulses. If PDM is pictured as PAM turned on its side, it is clear that the detection of PDM may be done the same way as PAM.

Figure 11 shows a suggested filter. The nominal cutoff frequency is 3 kc/s; a 3-dB loss occurs at 3.1 kc/s, and a 20-dB loss at 3.5 kc/s. The ultimate loss is 50 dB, more or less, depending largely on how well the output terminal is isolated from the input. The characteristic impedance Z_c is 10,000 ohms.

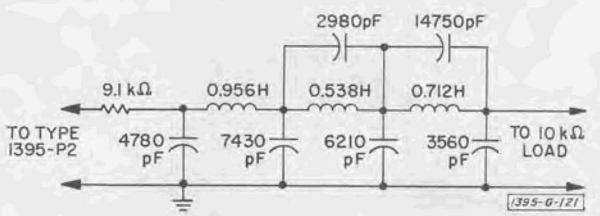


Figure 11. A 3-kc low-pass filter. Characteristic impedance is 10,000 ohms.

It may be asked why a characteristic impedance of 10,000 ohms is used with a Type 1395-P2 Unit that has an output impedance of 1000 ohms or less. The reason is chiefly to get a better oscilloscope presentation. A large resistor between the filter and the Pulse/Delay Unit output terminal ensures that the filter will not load the Pulse/Delay Unit in such a way as to change the appearance of the output pulses. An oscilloscope connected to the left of the 9.1-kΩ resistor in Figure 11 will give clear pictures of the modulation. Indeed, designers of PAM and PDM equipment usually choose filters with either a resistor or an inductor as the first element the signal encounters after it enters the filter. This allows the pulse shape going into the filter to be preserved and makes it easier to visualize what pulses at this point should look like if it is necessary to trouble-shoot.

The circuit of Figure 11 is offered as a good filter for those who wish to make their own. Commercial filters are also readily available. For example, the UTC LML series filters (500- or 600-ohm impedance level in and out) or the LMI series (10,000 ohms in and out) is suggested.

8 DETECTING PPM

Pulse-position modulation produces some audio within the pulse train itself, and so demodulating may be accomplished by simple filtering. However, the audio content of a PPM signal is far poorer than that of PAM or PDM. The recommended procedure for detecting PPM is to convert it first to PDM and then detect the PDM by filtering.

This conversion is made with a Type 1395-P3 Pulse Shaper. The setup is shown in Figure 12. Units 1 through 3 produce PPM in the manner described in Parts 3 and 4. The fourth unit in the chassis, the Pulse Shaper, acts as detector. It can perform this function because its output pulse is started and stopped by different signals. The shaping capability is of no significance in this application, and leading and trailing edges are set to be as fast as possible.

The *sync line* starts a pulse in the Shaper. This starting occurs at a uniform spacing in time. In the example shown, with a prf of 8 kc/s, a new pulse starts every 125 microseconds. The time the Shaper pulses stop, however, depends on when a PPM *signal line* pulse arrives, and this is a function of the modulation. Therefore, the duration of the Shaper output pulses is likewise a function of the modulation, and the PPM is converted to PDM. Filtering completes the detection, as already described.

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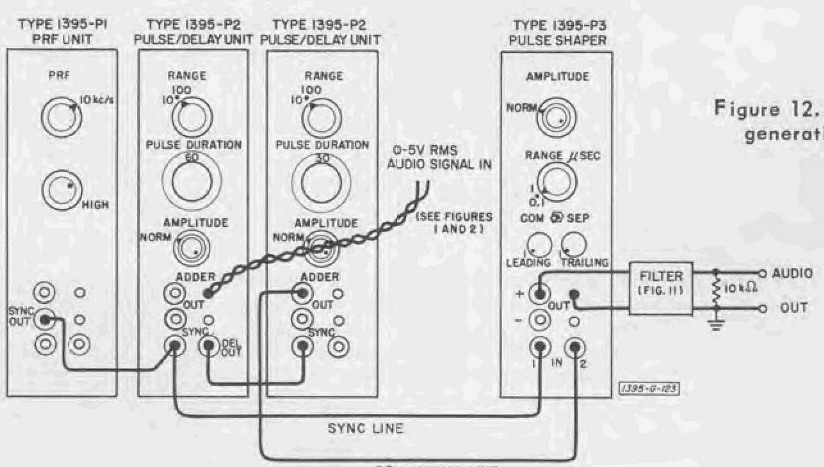

Figure 12. Module interconnections for generation and detection of PDM.

APPENDIX

The term "modulated pulses" refers to pulses in which some property has been altered in response to a signal carrying information.[1] The fundamental properties of pulses are their repetition frequency, amplitude, duration (often called "width"), and indeed whether or not the pulses even exist. These properties are convertible into the usual types of pulse modulation, namely (a) pulse position modulation or PPM, (b) pulse amplitude modulation or PAM, (c) pulse duration modulation or PDM, and (d) pulse code modulation or PCM. Let us examine these modulations in more detail.

(A) Pulse Position Modulation or PPM. A train of pulses left undisturbed consists of periodically repeated bursts of energy, usually generated in an on-off fashion

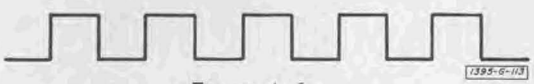

Figure A-1.
Unmodulated pulses.

so that energy is either present in a fixed, predetermined amount, or absent altogether. On an oscilloscope, such a train of pulses would look like Figure A-1. Ideally, the pulses are rectangular. In practice, they are slightly trapezoidal because it is impossible to develop a leading edge rising in zero time, or, likewise, an instantaneous trailing edge. All the pulses are of the same amplitude and duration, and exactly the same time interval separates pulse 1 from pulse 2, pulse 2 from 3, or pulse n from pulse n + 1.

In Figure A-2, not all the idealized assumptions prevail. Indeed, the last one regarding uniform spacing has been altered on purpose. The true centerlines of the pulses indicated by ℄ no longer coincide with where the centerlines would be if the pulses were left alone. These nominal, uniformly spaced centerlines are marked by the symbol ℘ representing "pseudo-centers". Note that the centerlines change position relative to the pseudo-centers from one pulse to the next. This change is the result of modulation and constitutes the information-carrying attribute of the pulse train.

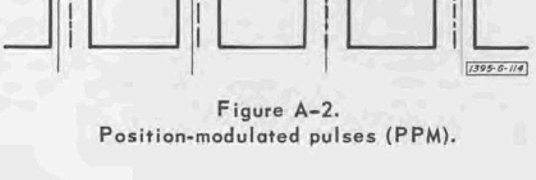

Figure A-2.
Position-modulated pulses (PPM).

We assume in this application note that modulation is at audio frequency. This need not be true in a specific system, of course, but it is convenient to speak of "audio" as the modulat*ing* signal, just as we speak of pulses as the *carrier*.

In Figure A-2, the properties of the audio signal are impressed on the pulse train as follows: The *amplitude* of the audio is represented by *how far* the centerlines move from the pseudo-centers. The audio *frequency* determines *how often*, i.e., how many times per second, this motion of the centerlines occurs.

Note the analogy between the PPM train and the concept of fm used with trains of sine waves. In fm, information is carried by slight variations in spacing between one cycle of the sine wave and the next; a given cycle is shortened or stretched slightly in response to modulation. In the PPM pulse train, the individual pulses are all alike, but the spacing between them varies.

(B) Pulse Amplitude Modulation or PAM. Pulse amplitude modulation consists of variations in the amplitude of individual pulses in a train in response to the modulating signal. A PAM train is sketched in Figure A-3. The analogy with conventional amplitude-modulated signals is evident from the illustration. PAM is a fairly simple, obvious form of pulse modulation and, like its sine wave relative, amplitude modulation, is fairly vulnerable to disturbance from noise.

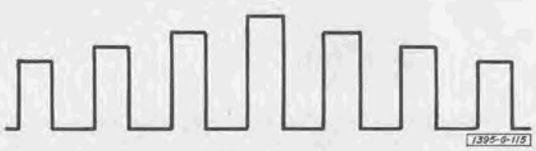

Figure A-3.
Amplitude-modulated pulses (PAM).

The audio amplitude in PAM is represented by how much the pulses depart (either increasing or decreasing) from their nominal amplitude. The audio frequency is represented by how often this departure from nominal occurs.

(C) Pulse Duration Modulation or PDM (PWM). In pulse duration modulation, the audio intelligence is carried by variations in how long the various pulses in a train last. The audio amplitude determines how much variation there will be in the pulse duration. The audio frequency controls how often this variation takes place. A PDM is sketched in Figure A-4. Note that the times

Figure A–4. Duration-modulated pulses (PDM).

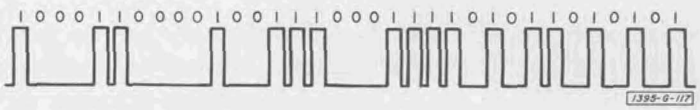

Figure A–5. A PCM sequence.

between leading edges of the pulses, t_1, t_2, etc, are all equal, but the pulses themselves vary considerably in duration. Such a pulse train viewed on an oscilloscope synchronized to the uniformly-repeating leading edges looks like a sequence of pulses varying in width. Therefore, PDM is often called pulse width modulation or PWM.

(D) Pulse Code Modulation or PCM. Pulse code modulation is the most complicated type of pulse modulation, uses the most bandwidth, and is the most immune to noise. It consists of the transmission of intelligence by periodic sampling of the audio waveform, storage of the sample as an analog voltage, generation of a sequence of digits representing (usually in binary form) the amplitude of the stored sample, and, finally, transmission of this digital number. The amplitude of the audio signal is represented by the number, and the frequency of the audio signal by how long it takes to go from a small number to a large number and back to a small one. One such sequence of small to large to small represents a cycle of the audio signal.

A true PCM train will constantly change its pattern. Electrically, this continual changing is accomplished by the use of an analog-to-digital converter or *encoder.* The General Radio Type 1395-P6 Word Generator simulates a PCM train by allowing the user to predetermine the existence of pulses by the setting of front-panel switches. As many as 16 binary digits (bits) may be set up on one Type 1395-P6 unit, and up to seven units may be connected in cascade. Therefore, a binary word length of $16 \times 7 = 112$ bits is possible in a Type 1395-A. The Word Generator module is not a true encoder: it cannot be modulated by an electrical signal. On the other hand, it is often essential in the design of digital equipment to set up a pattern that will remain fixed so that known test conditions prevail. An example of a PCM train is shown in Figure A-5. The presence of a pulse represents binary 1; the absence of a pulse is a binary 0.

PCM is such a specialized type of modulation that we will not discuss it further here, but there are many references in the literature. Oliver, *et al*[2], is something of a classic and is recommended for general background.

REFERENCES

1. A suggested reference work for the theory of modulation, including pulse modulation, is Harold S. Black, *Modulation Theory,* D. Van Nostrand Company, Inc., New York, 1953.

2. Oliver, B. M., J. R. Pierce, and C. E. Shannon, "The Philosophy of PCM," *Proceedings of the IRE,* Vol 36, No. 11, p 1324, November, 1948.

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