CONFIGURING TELEMETRY SYSTEMS FOR HIGH-POWER-MICROWAVE TESTING

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ABSTRACT

During high-power microwave (HPM) testing, where the item under test is subjected to power levels up to several thousand W/cm^2, the RF energy present will make typical telemetry RF links useless. Therefore, other means must be used to retrieve the data during the tests. One method to accomplish data retrieval is to replace the RF data link with a fiber-optic link. This is done by replacing the transmitter with a fiber-optic transmitter on the sending end and the RF receiver with a fiber-optic receiver on the receiving end. Although this sounds simple, it is not always so. Solutions for PCM and FM-FM systems are relatively straightforward, whereas PAM systems present a unique set of problems. This paper addresses possible solutions for PCM and FM-FM and three possible solutions for PAM, one being by using a PAM-to-PCM converter.

Key Words: High-power microwave (HPM), fiber optics, PAM-to-PCM converter.

BACKGROUND

High-power microwave (HPM) is a project that looks into the effects of microwave energy on various commercial and military systems. Almost every major system will undergo HPM testing sometime in the future. The purpose of this paper is to explain what HPM is and what is involved in configuring existing telemetry for HPM.

More and more microwave devices are being built and used every day: everything from microwave ovens to radar and satellite transmitting stations. Radio-frequency interference (RFI) in the microwave region is beginning to become a problem. To overcome this problem, power levels at microwave transmitting sites are being increased. The concern now is what is happening to surrounding systems that are being subjected to high levels of

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microwave power. Everything from computers to airplanes that may cross a microwave field is being tested. The questions HPM is to answer are, Does a system fail in the presence of microwave; and, if so, at what power level and to what extent does it fail?

The configuration for the test consists of a nonconductive platform to hold the test article. An antenna array is focused on the test article with several klystrons connected in parallel to provide up to several thousand W/cm^2[1]. Under these conditions, a standard telemetry unit using RF transmitters to relay the data will not work. Energy can enter the transmitter through the antenna causing the transmitter to fail. A similar problem exists at the receiving end. The use of a coax or other cable having conductors will not work because of possible currents that will be induced by the RF field. Even if a coax cable could be found that would not be affected by the high-intensity RF field, it would present another problem. The outer conductor is usually connected to the test article body at one end and grounded at the receiver end. This would ground the test article body and invalidate the test. Therefore, one solution to the problem is to replace the RF transmitter with a fiber-optic transmitter.

Fiber-optic cables are relatively immune to electromagnetic radiation. But as the microwave power increases, X-rays are generated along with RF. The X-rays may cause the data on the fiber-optic cable to be interrupted for the duration of the pulse unless the cable is lead-shielded. There is, however, no danger of having the microwaves enter the test article through the fiber-optic cable rendering the telemetry unit useless as would be the case with an antenna or a coax cable. Fiber-optic cables are also totally isolated from the ground so the test will not be violated. The characteristics of fiber-optic cables make them a good choice for this application.

DISCUSSION

Now that it has been established that fiber-optic cables are “the way to go” for this test, what types of transmitters and receivers are on the market and how can we integrate them into an existing system? Basically, the two types of transmitter-receiver pairs are analog and digital. Most telemetry systems are FM-FM, PCM, PAM, or a combination of the three. Now, what type of fiber-optic system best fits the existing telemetry system?

Analog Systems

Almost all analog transmitters are intensity modulated (IM), the light intensity being modulated according to the input signal. Light-emitting diodes (LED) used as the light source are nonlinear. The LEDs are biased at a quiescent point—similar to biasing a transistor circuit. Care must be taken not to overdrive the LED so as to cause it to go into cutoff or saturation, which will cause distortion[2].

Analog receivers use photodetector diodes in which current varies with intensity. A common front-end circuit is a transimpedance amplifier (Figure 1). This circuit converts the current flowing through the photodiode into a voltage[3]. One drawback is that it is usually AC-coupled because the bias current through the photodiode varies with temperature.

Most commercially available analog systems have an input impedance of 75Ω and an input voltage of 1 $V_{p\text{-}p}$. The receiver output impedance is either 50 or 75Ω[*,**]. This system can be modulated in three ways. First is baseband IM, in which the input signal is directly inputted into the transmitter. The drawback here is that the DC component of the signal will not be conserved, because of the AC coupling at the receiver end, and the fiber has only one channel of information. AM-IM is another method, in which the signal is AM-modulated on carrier and then fed into the transmitter. The advantages here, of course, are that the DC level is conserved and other AM signals at different carrier frequencies can be mixed, and one fiber can carry many channels. The last method is FM-IM, which is exactly like AM-IM except that a carrier frequency is frequency-modulated with the signal[4]. This method is identical to FM-FM, except that the RF transmitter has been replaced by a fiber-optic transmitter. The problem here is that the mixer output cannot drive the 75-Ω input impedance of the fiber-optic transmitter. A buffer circuit will have to be built to drive the transmitter with its output-voltage swing set to 1 $V_{p\text{-}p}$. This solves the case for an FM-FM system (Figure 2).

Digital Systems

There are three ways, we are interested in, to modulate a digital signal. The first is on-off keying (OOK). In this scheme, the LED is either on or off. When using OOK for NRZ, care must be taken to avoid long strings of “0s” or “1s”, which could cause a DC offset at the receiver end because the signal could be AC coupled[5]. This is the simplest configuration for a straight PCM system. All that is required is to replace the RF with a fiber-optic transmitter (Figure 3). No buffering or other signal conditioning is required.

Frequency-shift keying (FSK) and phase-shift keying (PSK) are the two other methods used in digital systems and are similar to each other. FSK is a system in which f1 represents a “0” and f2 represents a “1”. In PSK a “0” is 180 degrees out of phase with respect to a “1”[6]. FSK is similar to a PCM-FM-FM system. The PCM stream first would be frequency-modulated at a carrier frequency and could be mixed with other signals with different carriers in a mixer. The mixer output then would be fed into a buffer,

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**Data Sheets. Meret, Inc. 1815 -24th Street, Santa Monica, CA 90404.

then into an analog fiber-optic transmitter (Figure 4). This method is not recommended for a simple PCM system because of the additional equipment that would be required to decommutate the signal, but it is perfect for PCM-FM-FM systems.

PAM Systems

PAM is another story. The DC level on PAM is always changing. No part of the signal can be clamped because the signal can be greater than 100% and can be less than 0%. Almost all fiber-optic receivers are AC-coupled because the bias current through the detector diode varies with temperature. With PAM, the DC level has to be conserved to have some accuracy when the signal is decommutated. Therefore, few, if any, commercially available fiber-optic systems can be hooked up to a PAM commutator the same way as FM-FM and PCM.

This problem can be solved in one of three ways. First is the strong-arm method. That is, convert, or build the transmitter and receiver so that they are DC-coupled (Figure 5). The transmitter input impedance also needs to be greater than 3kΩ. When a DC-coupled receiver is built, care must be taken to compensate for the temperature drift. One way is to build the receiver with a transimpedance amplifier and make a straight-line approximation on the detector-current drift with respect to temperature and use a linear temperature-compensation circuit on the other lead. Again, care must be taken not to overdrive the transmitter's LED or the receiver's photodetector as this will cause distortion. Obviously, a great deal of work is required. There are easier ways to get the data down the line.

The second method is to frequency-modulate the PAM signal before feeding it to an analog transmitter (Figure 6). This method would be perfect for systems that have other analog channels at different carrier frequencies that could be mixed. The system would be similar to a PAM-FM-FM system. For a simple PAM system, this means that a discriminator that is usually not there would be needed at the receiving end.

The third method is to use a PAM-to-PCM converter. A PAM-to-PCM converter board has been developed at the Naval Weapons Center. The NAVWPNCEN-developed board directly converts a PAM train into a PCM stream. This is done by feeding the PAM into a sample-and-hold (S/H) circuit so that an analog-to-digital (A/D) conversion can be made (Figure 7). A parallel-to-serial conversion is performed on the output of the A/D converter, and the output of the circuit is NRZL.

The control circuitry takes care of the timing of the sample-and-hold circuit, of the A/D converter, and of the shift registers. The PAM-to-PCM converter board has a 2-MHz clock. The clock is divided to provide the PAM clock for the commutator. Since the controller provides the clock to the commutator, it knows when a newword appears at the sample-and-hold circuit. The controller then sends the A/D converter a convert pulse at the middle of the PAM word when the amplitude should be stable. The A/D converter tells the S/H to hold its value while the A/D makes a 10-bit conversion where 0% is 256 counts and 100% is at 768 counts. This conversion allows for the over and under shoots that can occur in PAM.

Once the conversion is made, the controller loads the shift register with the output of the A/D converter. While this process is taking place, the data from the previous word is being clocked out to produce the PCM NRZL. The process then repeats itself until the controller circuitry receives a PAM frame sync pulse from the commutator. When this occurs, the controller inserts PCM frame sync words in the second and third full-scale words of the PAM sync pattern (Figure 8)[(7)]. This process will make it possible to decommutate the signal using standard PCM decommutators. The 0%, one of the 100%, and the 50% levels are sent to provide calibration readings.

One big advantage to this approach is the readily available supply of PCM decommutators. A decrease in the use of PAM has led to a corresponding decrease in the availability of PAM decommutators. The accuracy of the system can also be improved with the use of the PAM-to-PCM converter. Finding people to do data reduction on PAM is also becoming more difficult. The best part about it is that the output of the PAM-to-PCM converter is TTL-compatible and can be connected directly to a digital fiber-optic transmitter (Figure 9).

CONCLUSION

HPM testing will probably be conducted on almost every major commercial and military system. Because of the presence of high microwave energy, typical telemetry systems that use RF links are made useless. The answer to this problem is to substitute the RF link with a fiber-optic link. The basic methods of modulation are FM-FM, PCM, and PAM. Each of these methods of modulation was discussed as to how each would be employed in a fiber-optic system. For an FM-FM, PCM-FM-FM, and PAM-FM-FM system, the solution was to buffer the output of the mixer before driving an analog fiber-optic transmitter. For the simple PCM system, the solution is to swap the RF for fiber-optic components. Simple PAM systems require us to employ other techniques such as frequency-modulating the PAM signal or converting it to a PCM signal before using one of the commercially available fiber-optic systems.

REFERENCES

1. Naval Weapons Center. "Final Test Plan for Microwave Exposure Test," by Warhead Development Branch. China Lake, Calif., NWC, July 1988. NWC Reg Memo 3261-077-88 (A).

2. Palais, Joseph C., 1988. Fiber Optic Communications, Second Edition, Prentice Hall, Englewood Cliffs, N. J., pp. 130-31.

3. Ibid., pp. 257-58.

4. Ibid., pp. 217-20.

5. Ibid., pp. 220-21.

6. Ibid., pp. 223-24.

7. Telemetry Group Range Commanders Council. "Telemetry Standards," IRIG 106-86. White Sands, N. M., TGRCC, May 1986, P. 5-2.

NOMENCLATURE

AC	alternating current
A/D	analog-to-digital (conversion)
DC	direct current
FM	frequency modulation
FSK	frequency-shift keying
HPM	high-power microwave
IM	intensity modulation
k	kilo- (prefix, 10^3)
LED	light-emitting diode
MHz	megahertz
NRZ	nonreturn to zero
NRZL	nonreturn to zero level
NAVWPNCEN	Naval Weapons Center
OOK	on-off keying
PAM	pulse-amplitude modulated
PCM	pulse-code modulated
PSK	phase-shift keying
p-p	peak-to-peak
RF	radio frequency

RFI	radio-frequency interference
S/H	sample-and-hold (circuit)
TYL	transistor-transistor logic
V	volts
Ω	ohm

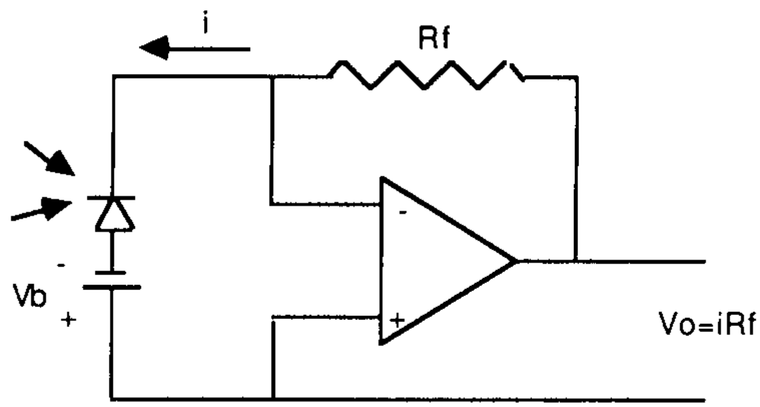

Figure 1. Transimpedance Amplifier (3).

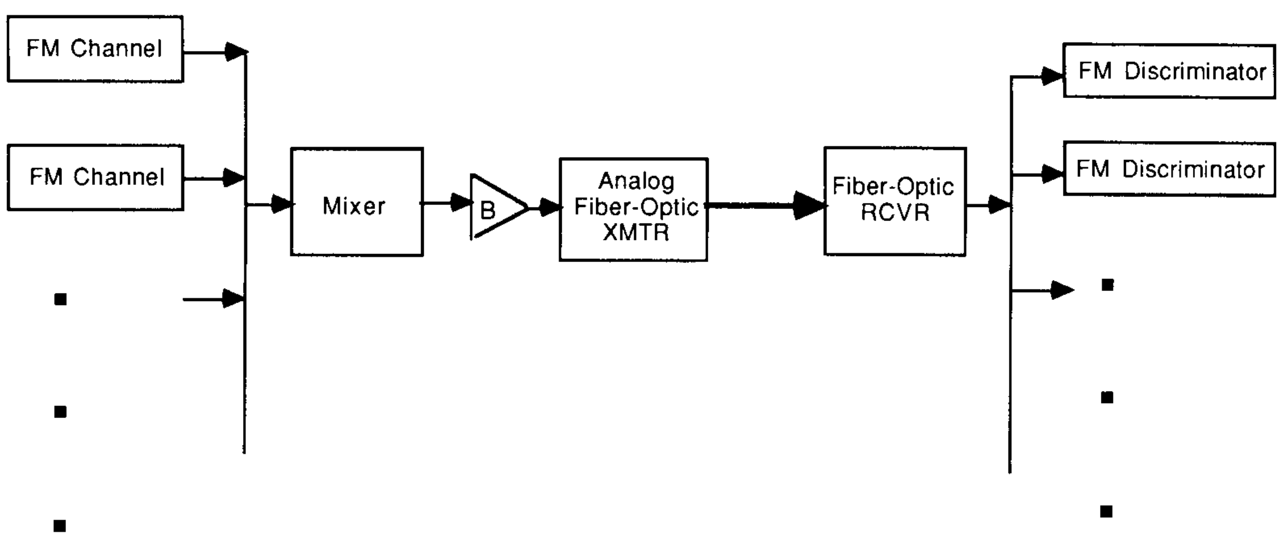

Figure 2. FM-IM Fiber Optic System.

Figure 3. Simple PCM System Using Digital OOK Fiber-Optic System.

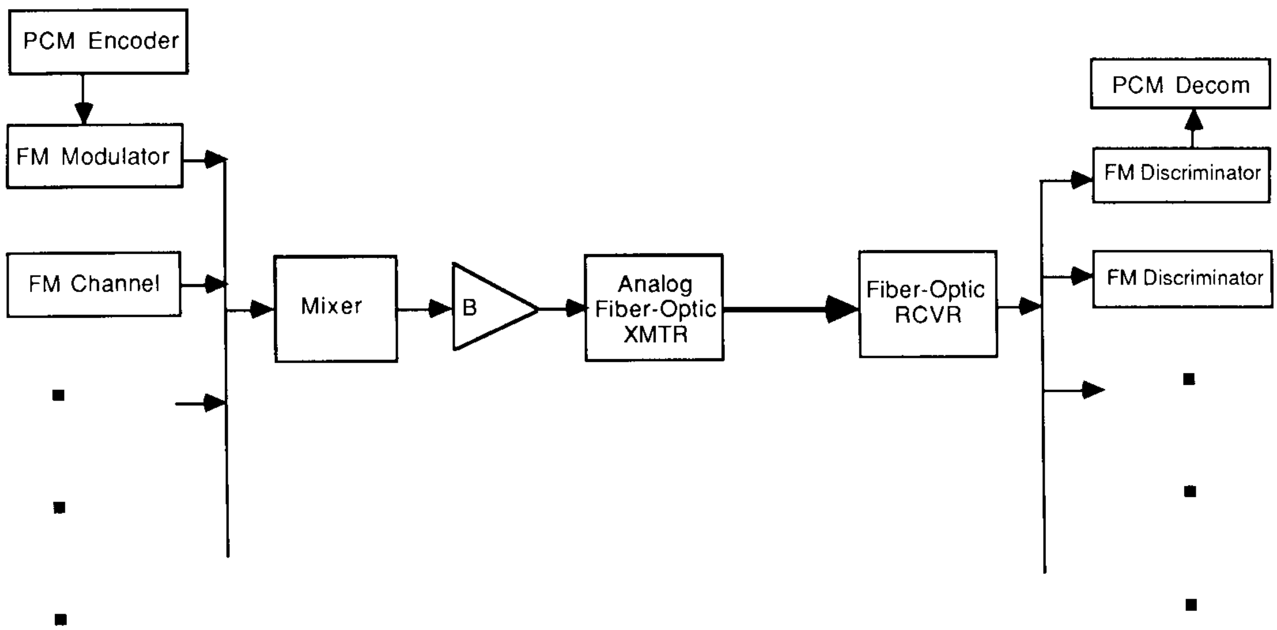

Figure 4. PCM-FM-IM Fiber-Optic System.

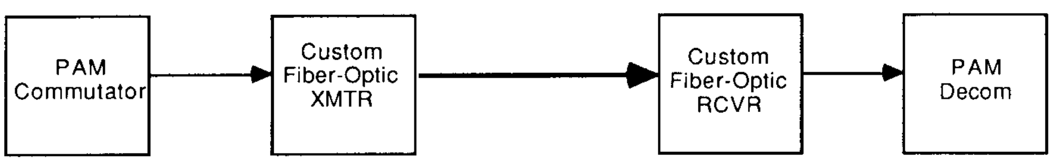

Figure 5. A PAM System Using an Anolog Fiber-Optic System That Conserves the DC Level.

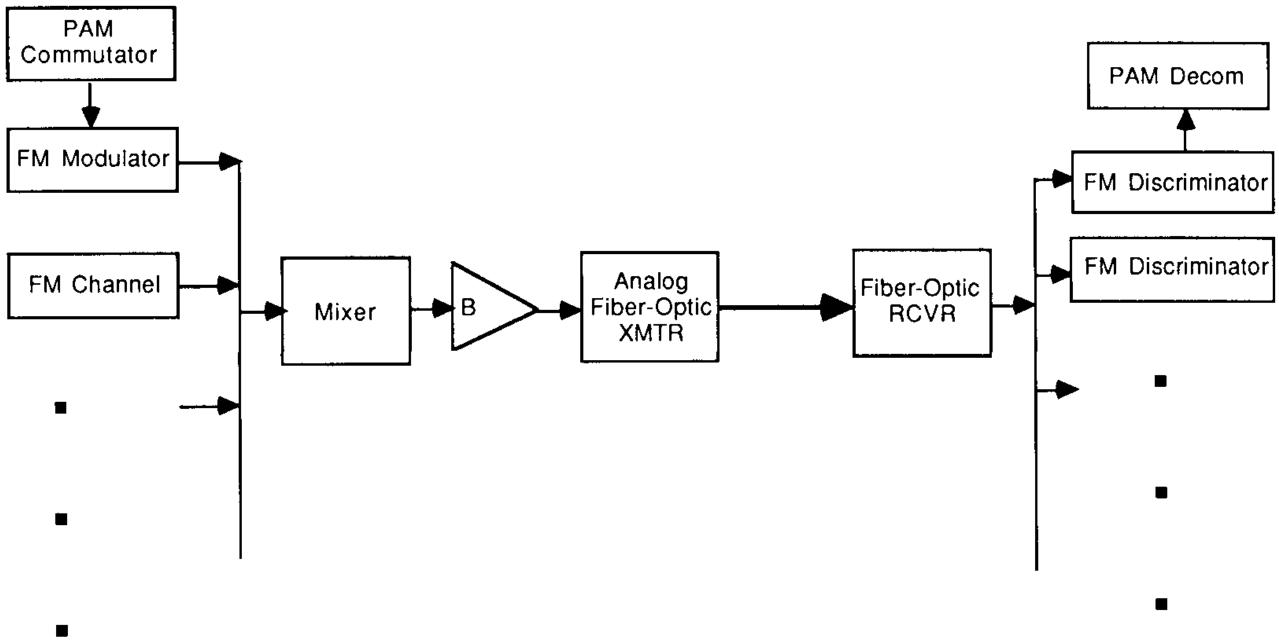

Figure 6. PAM-FM-IM Fiber-Optic System.

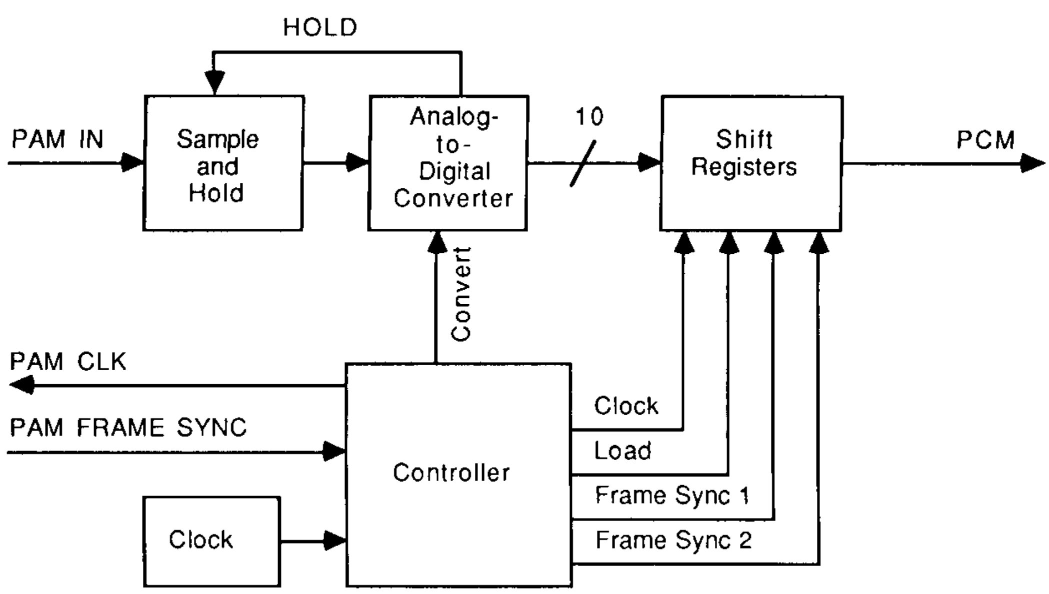

Figure 7. Block Diagram of the PAM-to-PCM Converter.

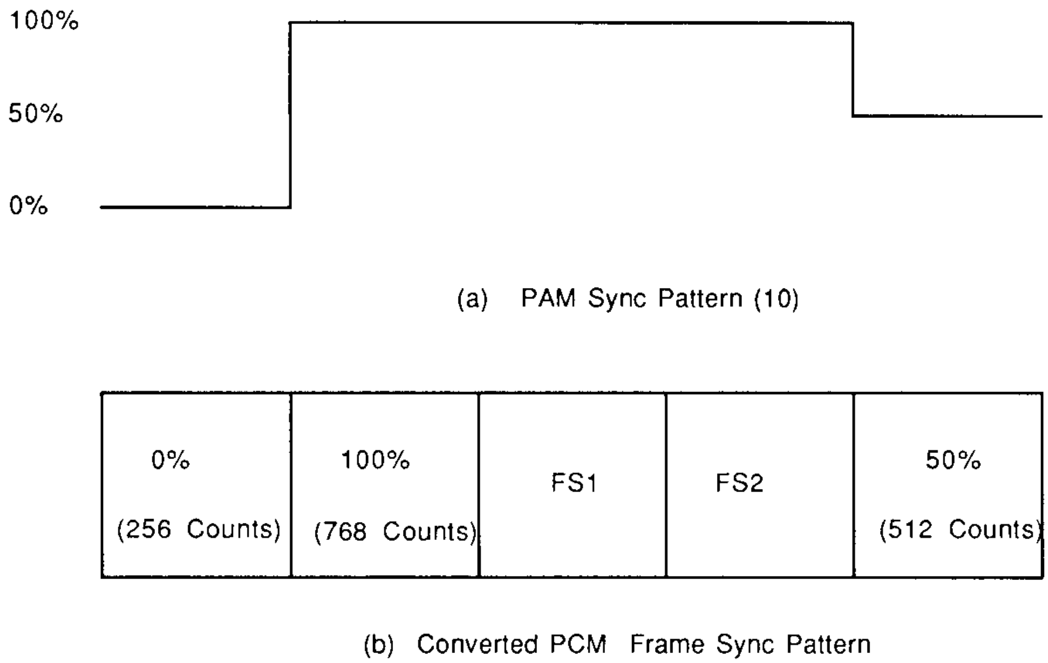

Figure 8. A PAM Sync Pattern Converted into a PCM Frame Sync Pattern.

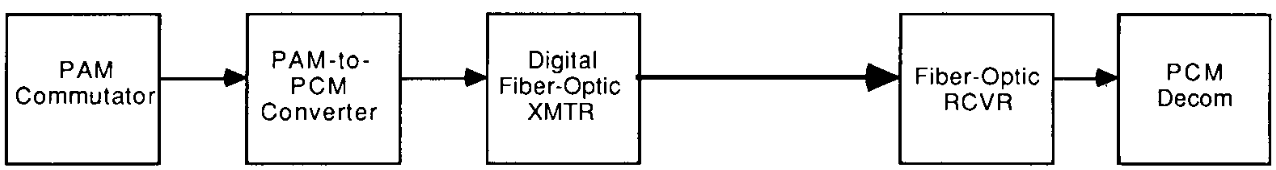

Figure 9. PAM Train Converted to PCM to Transmit Data With a Digital Fiber-Optic System.