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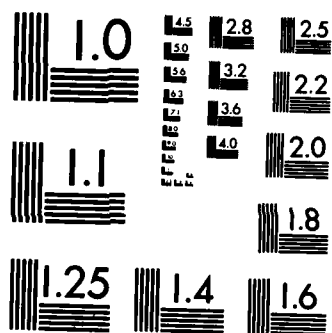
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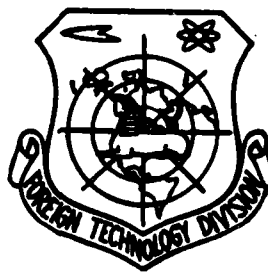
FOREIGN TECHNOLOGY DIVISION



FIBER OPTICS IN AIRCRAFT APPLICATIONS

by

Wang Wenying



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FIBER OPTICS IN AIRCRAFT APPLICATIONS

Wang Wenying

The optical fiber is a transmission medium with extensive usages. If properly designed, the fiber can replace twisted copper wire cable, coaxial cable, and metal waveguide.

In fiber optics, the sending and receiving devices have been generally standardized: the light emitting diode (LED) and laser diode (LD) are used for the light source at the sending end, and the photoelectric diode (PD) and avalanche producing diode (APD) are used for detectors at the receiving end. Two combinations of LED-PD and LD-APD are also used.

The spectral width of the strip-shaped AlGaAs transmission is relatively narrow when it is used in the laser; the spectral width is less than 2 millimicrons, and the width for the LED is 35 millimicrons. The modulation bandwidth of AlGaAs for laser transmission is relatively greater, approximately 500 megahertz, and the bandwidth for the LED is 50 megahertz. In addition, the power required for coupling the AlGaAs with multimode optical fiber is greater, approximately 1 milliwatt (compared to 100 microwatts for the LED). Therefore, the strip-shaped AlGaAs (used in laser transmission) is appropriate for medium to high transmission speed, and for a digital system with a distance exceeding several kilometers.

Within a certain range, the light intensity of the high-brightness Burrus Model LED is proportional to the positive direction current; therefore, the light intensity can be modulated directly with an exciting current of 50 megahertz frequency. Besides, the LED has a long service life, good stability and low cost. Thus, the Burrus Model LED has been extensively applied in aircraft.

Within the wavelength range of 0.8 to 0.9 micron, the highly sensitive and fast response silicon photoelectric diode can be used as a detector. Although the PIN photoelectric diode has no increment, it is still properly used over a short distance since in that case the receiver sensitivity is not the main consideration.

The APD can amplify the original current of the signal light, thus increasing sensitivity of the receiver. However, additional (unwanted) noise is introduced because the amplification process is random; the noise increases with the increment. Therefore, there is a problem of optimized increment value for maximum sensitivity for a certain operating condition. Besides, the APD requires somewhat high voltage (100 to 400 volts) of the base electrode, and the diode increment varies significantly with temperature at a high increment. Therefore, compensation for temperature variation during operation should include an automatic increment control feedback ring.

At present, the LED-PD combination is extensively applied in aircraft fiber optics.

THE DEFINITE TREND OF FIBER OPTICS IN AIRCRAFT APPLICATIONS

After composite materials are used for covering the skin of aircraft, problems of countermeasures against electromagnetic interference/impact and nuclear radiation have been more and more noticeable. The sole method of solving these problems is the use of optical fiber for the transmission line because the fiber is a medium material, which does not radiate energy

and does not have ground circulating current (and the instantaneous disturbance thus produced). In addition, the transmission capacity of an optical fiber system is great; only a single conduit of optical fiber can transmit messages of video frequency, acoustical frequency, and digital data.

There are many reasons why up to now fiber optics has not been widely applied: insufficient standard, norm, experience, and key components required. Another reason is the relatively high price. Although the price of optical fiber is competitive with coaxial cable having similar characteristics in ground communications systems, the price is higher than the cheap double twisted wire. However, if the bandwidth characteristics of optical fiber are utilized, and through repetitive use, hundreds of signal channels can be transmitted by a single optical fiber, the price becomes very competitive. Moreover, the price of optical fiber has a downward trend, while that of copper may rise. Therefore, the single fiber signal channel may be in a competitive position with the double twisted wire.

OPTICAL FIBER DATA TRUNK LINE

The optical fiber data trunk line is composed of terminals connected to the data trunk line. Every terminal can receive a signal message through the data trunk line, and can send a signal (through the trunk line) to any other terminal or the central control device. While directly sending or receiving signals to other terminals through the central control device, every terminal is allotted a time segment. The optical fiber data trunk line not only is simple in connections but also has the potential for expansion.

Different from a metal wire data trunk line, the optical fiber trunk line has no ground [return] circuit, and is thus free from oscillations caused by the ground circuit; no adjustment circuit is required. In addition, the characteristics (of the optical fiber trunk) of a wide frequency band

and low attenuation can eliminate the use of relay devices even for a long distance between terminals; the optical fiber can transmit at a very high data rate [baud]. Besides, the optical fiber data trunk line has the advantages of antielectromagnetic impact and interference.

Hence, applications of the optical fiber data trunk line are quite extensive: in computers and peripheral equipment, in computers and data transmission, in a distributed processing system, in avionic equipment, and in systems of tactical command, control and communications (C^3).

Figure 1 shows the layout of an optical fiber data trunk line in an aircraft. Figure 2 shows three connection methods of the optical fiber trunk line.

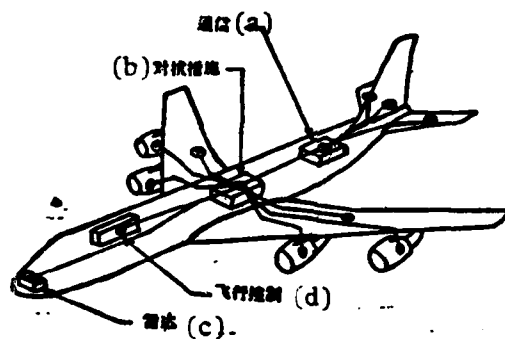


Fig. 1. Optical fiber data trunk line in an aircraft.
Key: (a) Communications; (b) Countermeasures; (c) Radar; (d) Flight control.

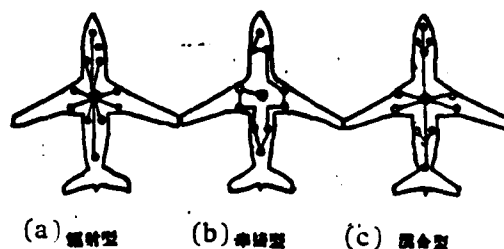


Fig. 2. Types of optical fiber data trunk line.
Key: (a) Radiate type; (b) Series connection type; (c) Mixed type.

In a series connection type trunk line, there is a Model T coupler for each terminal. The loss between two terminals of a trunk line increases according to an index law with the number of couplers. Hence, the greater the insertion loss of the series connection type trunk line, the greater is the range of signal activities as shown in Table 1. Therefore, generally the series connection trunk line is not used. The radiate type trunk line can satisfy requirements concerning characteristics, but this type of trunk line is very easily damaged and requires a long cable. The mixed type data trunk line has the advantages of other two types, thus meeting the requirements of lower system complexity.

Table 1. Comparison of three types of trunk lines.

参 (a) 数	串接型总线	辐射型总线	混合型总线
插入损耗 (分贝) (b)	(g) 360	(h) 30	(i) 30
信号范围 (OSR) (分贝) (c)	~350	<2	~23
所需耦合器数 (d)	30	1	2
所需连接器数 (e)	154	128	98
所需电缆长度 (米) (f)	100	800	450

Assumptions: 32 stations; distance between local terminals, 20 meters; maximum cable laying length, 6 meters (with average of 4 meters); cable attenuation (optical fiber), 100 db/km.

Key: (a) Parameters; (b) Insertion attenuation (db); (c) Output signal range (OSR), db; (d) Number of couplers required; (e) Number of connectors required; (f) Required cable length (m); (g) Series connection type trunk line; (h) Radiate type trunk line; (i) Mixed type trunk line.

As for the expenses of the trunk line, it is more appropriate to use an optical fiber data trunk line for large systems with high data rate because no relay stations are required and the cable expenses are relatively low.

There are many cases of aircraft applications of data trunk lines, referring to the following examples:

As early as 1974, the US Air Force conducted tests of the radiate type data trunk line (in remodeled C-131 aircraft) for transmitting multichannel repetitive use flight control signals. These tests were done with the coordination of Air Force multichannel repetitive use project. The purpose is to develop a multichannel repetitive use data transmission system for connecting avionic devices, to lower wire weight and volume, as well as to increase mobility and adaptability of the system.

The US Air Force conducted a research project, Fiber Optics Communications Applied to Space (FOCAS). The most modern part of the project is the data trunk line, using 19-wire plastic covered silica (PCS) fiber strands made by the Valtec Company. The system was tested in RC-135 aircraft.

In the navy, applications of the optical fiber data trunk line are concentrated on improving optical fiber elements suitable for data trunk line layout. The research results were applied to FY78 aircraft. The purpose of the data trunk line project in navy aircraft is to achieve an operational level for elements required by vertical and short distance takeoff and landing aircraft.

Figure 3 shows a digital control system of tactical aircraft (DIGITAC) using the US military optical fiber data trunk line. This is a double channel flight control system, controlled by two microcomputers.

Each strand of fibers used in the DIGITAC system contains 210 optical fibers, 45 mils in diameter. The length of the fiber strand is determined by aircraft size--10 to 12 feet (for the length of the optical fiber strand) in A-7 aircraft. Later, it is planned to use 125 microns as the wire diameter, and 200 microns as the envelope layer (of the optical fiber) in the DIGITAC system; the LED-PD layout is used in the light source and detector.

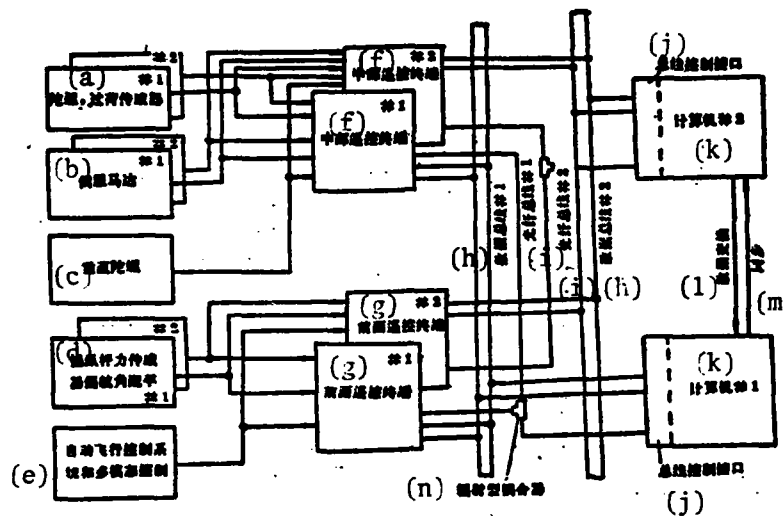


Fig. 3. Schematic diagram of DIGITAC II optical fiber system.

Key: (a) Gyroscope, overload transmitter; (b) Servomotor; (c) Vertical gyroscope; (d) Control rod force transmitter leveling with crab angle; (e) Automatic flight control system and multimode control; (f) Middle part remote control terminal; (g) Forward part remote control terminal; (h) Data trunk line; (i) Optical fiber trunk line; (j) Trunk line control port; (k) Computer; (l) Data exchange; (m) Synchronizing; (n) Radiate type coupler.

OPTICAL FIBER COMMUNICATIONS

At present, the composition of minimum avionic equipment is as follows: three radio transmitting and receiving sets (modulating frequency, very high frequency, and ultrahigh frequency), and two intercoms and radio navigation direction indicators. All input/output terminals of radio equipment are wired to a connection box, which provides connecting ports between intercoms, between radio and intercoms, between earphones, and between receivers and intercoms.

Generally, single wires, double twisted shielded wires, or coaxial cables are used for interconnections of avionic equipment and the firing

control system. Under normal conditions, these wiring connections are reliable; however, these connections become unreliable under electromagnetic interference and artificial electronic interference.

Optical fibers can connect a point-to-point channel; the fibers can withstand electromagnetic interference and high temperature up to 1000°C. No electric spark or short-circuit loading exists on the optical fibers.

If all point-to-point communication lines are replaced with optical fibers, then each line requires optical cable, LED and PD. Thus, the one-to-one replacement expenses are too high. Generally, multichannel repetitive-use lines are used in communications.

The remote control automatic steering system of a large load hoisting helicopter uses double twisted shielded cable in a point-to-point communication system. The system is more reliable once optical cable replaces double twisted shielded cable.

In 1977, the US Air Force completed a wide band optical fiber data transmission project. The purpose of the project is to certify the capacity of optical fibers while transmitting high-frequency signals by using then available components, and to design and establish two different models of a wide band point-to-point optical fiber communication system. One is the high data rate digital system; the other is the (digital modulation) simulated high frequency FM carrier wave system. The GaAs LED, multimode optical-fiber strand, and silicon PIN PD are used in design. In every system, measurements are conducted on different models of optical fiber strand.

The optical fiber communication system uses Valtec optical-fiber strands with attenuation of 11.2 db/km. It was measured that the maximum data rate of the digital system is 142 megabits per second. By using a similar optical fiber strand, the highest carrier frequency of the FM line is 290 megahertz. In digital electronic components of a receiving

set, the restrictive component of the digital line is the Manchester decoding circuit. In the FM system, the restrictive component is the LED/exciting stage of FM transmitter.

In December 1975, the US Air Force announced a wide band optical fiber data transmission project for flight. This was the first application of optical fiber wide band in the flight environment. Two point-to-point optical fiber simulated lines were installed on combat aircraft; one is the video frequency and the other is an intermediate frequency. In the former case, 20 megahertz baseband video frequency signals are transmitted between two points, 18.3 meters apart. In the intermediate frequency line, the optical cable line is 30.3 meters long, operating at a 160 megahertz carrier frequency and 29 megahertz bandwidth. These two lines use Voltec 19-wire plastic-covered pure melted silica strands. The testing/operation temperatures of these two systems are between -54°C and +95°C. Since the range of temperature variation is great, no plastic covered optical fibers can be used. It should be noted when using LED that a large range of temperature variation will affect service life or lower the characteristics.

DATA TRANSMISSION LINE OF OPTICAL FIBERS

A data transmission line is also a communication line. Applications of fiber optics in navigation guidance and weapon release systems are introduced in the following:

Figure 4 shows the electric connection diagram of navigation and weapon release systems in A-7 aircraft. The system uses 302 wires (double twisted shielded wires, three-strand wires, and coaxial cables) to compose a signal transmission line. There are eight transmission signal types (simulated, digital, divergent, pulse sequence, and switch locking) and 115 channels of signals (1 channel of simulated signals and 114 channels of digital signals).

In March 1974, the US Navy began to pursue a project on airborne light optical fiber technique (ALOFT) by using optical fiber technique in

navigation and weapon release systems of A-7 aircraft. The project was concluded in February 1977 after 107 hours of flight tests.

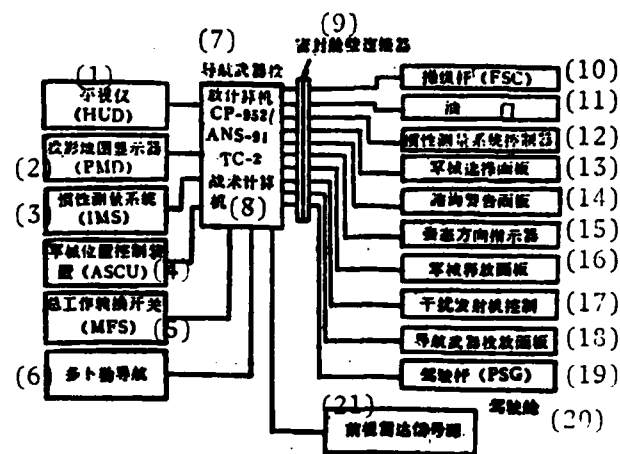


Fig. 4. Electrical connection diagram of A-7 navigation and weapon release systems.

Key: (1) Horizontal utiliscope device (HUD); (2) Projection map display (PMD); (3) Inertia measurement system (IMS); (4) Armament signal control unit (ASCU); (5) Main field switch (MFS); (6) Doppler navigation; (7) Navigation and weapon release computer; (8) Tactical computer; (9) Sealed cabin wall connector; (10) Control rod; (11) Throttle; (12) Controller of inertia measurement system; (13) Armament selecting board; (14) Radio warning board; (15) Attitude and direction indicator; (16) Armament release board; (17) Interference to engine control; (18) Navigation and weapon release board; (19) Control stick; (20) Pilot's cockpit; (21) Source of forward search radar signal.

The project proved the feasibility of using the optical fiber technique in a military system. Figure 5 shows the layout of the ALOFT system; it uses an hour-minute multichannel repetitive use system and Manchester code. The 115 signals are transmitted by 13 optical fibers, and a single light connector is formed at the computer port. The maximum data transmission rate is 10 megabits per second. There are at most five coupled points between

the light source and light detector; the longest transmission distance is 8 meters. The GaAs LED is used as light source, and a PIN silicon photoelectric diode is used as light detector. The optical cable is made of intermediate attenuation glass-core glass-color-layer optical fibers with 1.1 millimeters as the diameter of the effective surface strand; the external diameter is 3 millimeters with the covering sleeve.

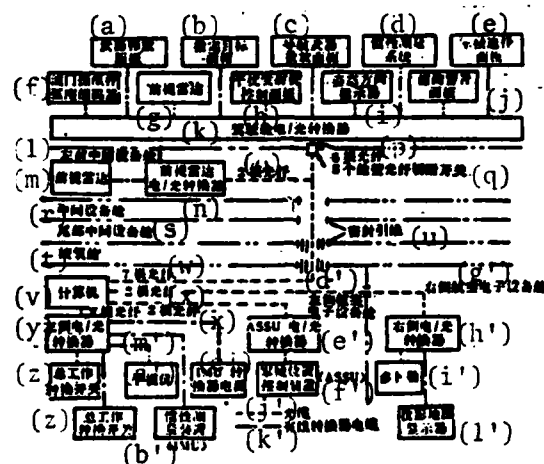


Fig. 5. Layout of ALOFT system.

Key: (a) Weapon release board; (b) Assigned target board; (c) Navigation and weapon release board; (d) Inertia measurement system; (e) Armament selection board; (f) Throttle control rod, Arc seat decoder; (g) Forward search radar; (h) Interference to engine control board; (i) Attitude and direction indicator; (j) Radio warning board; (k) Electricity to light converter at pilot's cockpit; (l) Front-left intermediate equipment cabin; (m) Front search radar; (n) Electricity to light converter in front search radar; (o) Two strands of optical fibers; (p) Five strands of optical fibers; (q) Five optical fiber cutoff switches at cabin wall; (r) Intermediate equipment cabin; (s) Tail portion intermediate equipment cabin; (t) Liquid oxygen cabin; (u) Sealed lead wires; (v) Computer; (w) Seven strands of optical fibers; (to be continued on following page)

(Fig. 4 continued)

(x) Two strands of optical fibers; (y) Left side electricity to light converter; (z) Main field switch; (a') Horizontal utiloscope device; (b') Inertia measurement unit (IMU); (c') Converter power source of IMU; (d') Left side avionic equipment cabin; (e') Electricity to light converter in ASSU; (f') Armament signal control unit (ASCU); (g') Right side avionic equipment cabin; (h') Right side electricity to light converter; (i') Doppler; (j') Optical cable; (k') Wired converter cable; (l') Projection map display.

There are five current converters (marked with heavy-line border) between the computer and avionic equipment (marked with fine-line border) as follows:

(1) Electricity-to-light converter (in pilot's cockpit) supplies all control consoles, displays and avionic devices in the pilot's cockpit.

(2) Right side avionic equipment cabin electricity-to-light converter supplies Doppler avionic equipment and projection map display (PMD).

(3) Left side avionic equipment cabin electricity-to-light converter supplies MFS board, HUD, IMS devices, and power source for IMS converter.

(4) ASCU electricity-to-light converter supplies ASCU in left side avionic equipment cabin.

(5) Intermediate equipment cabin electricity-to-light converter supplies forward search radar scanning producer.

Dotted lines indicate optical fibers, which connect the computer and electricity-to-light converters, transmitting 115 hour-minute multichannel repetitive-use signals. The dot-and-dash lines represent power converter cables, which connect avionic equipment and converters.

Seven out of 13 strands of optical fibers pass through the liquid oxygen cabin and the tail portion intermediate equipment cabin; these two cabins are dangerous cargo cabins. The optical fibers are safe to be passed through these cabins but electrical conduction wires should go around these cabins.

After optical fibers were used to transmit data in navigation and weapon release systems in A-7 aircraft, the system weight was reduced to 1/12 of the original amount; expenses were also reduced (see Table 2).

Table 2. Comparison between optical cable and electrical wire.

	(g) 导线	光纤 (多路复用)
(a) 导线/光纤数	302	(h) 13
(b) 电缆、连接器总重	14.46 公斤 (i)	1.2 公斤 (i)
总长度 (c)	576.07 米 (j)	68.27 米 (j)
(d) 电缆、连接器总费用	350 美元 (k)	790 美元 (k)
终端、试验费用 (e)	1280 美元 (k)	240 美元 (k)
(f) 总费用	1630 美元 (k)	1030 美元 (k)

Key: (a) Number of wires/(number of optical fibers); (b) Total weight of cable and connectors; (c) Total length; (d) Total expenses for cable and connectors; (e) Expenses for terminals and testing; (f) Total expenses; (g) Lead wire; (h) Optical fiber (multichannel repetitive use); (i) Kilograms; (j) Meters; (k) US dollars.

As used in ALOFT, all optical-fiber cables, LED and photoelectric diodes were tested in a temperature range of -62°C to $+95^{\circ}\text{C}$. Moreover, impact tests were conducted on vibration, shock, humidity, sea fog and temperature. As revealed in tests, the optical-fiber elements can withstand the assigned environment of tactical aircraft.

Besides, a series of electromagnetic compatibility and endurance tests were conducted on the optical-fiber system; the most strict was the simulated lightning discharge test. When a peak current value of 2000 amperes passes through the covering skin of an aircraft, the instantaneous variation value sensed in the optical fiber is lowered by eightfold than the original double shielded wire system.

As indicated by experimental results, accuracies of the multichannel repetitive-use optical-fiber system and of the multichannel wire system are the same under conditions free from electromagnetic interference or lightning discharge. However, the multichannel repetitive-use optical fiber system has better characteristics than the multichannel wire system under the condition of electromagnetic interference or lightning discharge. For computers connected by optical fibers, the voltage induced in them is 85 to 90 percent lower than the voltage induced in computers with wire connections under the simulated environment of lightning.

Also revealed in tests, no significant radiation is discovered in coupled installation of optical fiber cable and electronic devices within the frequency range of 14 and 50 megahertz. However, within the frequency range of 118 to 210 megahertz, radiation is discovered although it appears only instantaneously with no repetitions.

When an optical fiber system is acted on by the following electric fields, the data transmission line is not affected:

14 kilohertz ~ 35 megahertz	10 volts per meter
35 megahertz ~ 1 gigahertz	5 volts per meter
1 gigahertz ~ 10 gigahertz	5 volts per meter

As revealed in Table 3, the error rates of the optical-fiber multichannel repetitive-use system are only 1/500 of the non-multichannel system connected by wires.

For HUD and main measurement instruments and meters in a aircraft, no interference appears when the optical fiber system is under electromagnetic interference. When a single shielded wire is acted on by EMI, the quality drops rapidly; the increase in the error rate will certainly induce and show apparent lowering of quality.

With ALOFT certification on A-7 aircraft, it is planned by US military circles to use the data multichannel repetitive-use point-to-point optical fiber system in Harrier (AV-B8) aircraft.

Table 3. Comparison of error rate test results.

	数据传输时间 (分)	传输数据 (比特)	引起的错误 (错误数)	错误率 (错误/比特)
(a)受 EMI 作用光纤系统	20	2.6×10^7	(f)	$< 3.9 \times 10^{-8}$
(b)受 EMI 作用导线系统	1.67	2.1×10^6	42	2.0×10^{-8}
(c)不受 EMI 的作用	52	6.7×10^7	0	$< 1.5 \times 10^{-8}$

Remark: Tested power level: 20 amperes, 100 volts, and 10 pulses per second.

Key: (a) Optical fiber system affected by EMI; (b) Electric wire system affected by EMI; (c) Not affected by EMI; (d) Data transmission time (minutes); (e) Transmitted data (bits); (f) Induced error (number of errors); (g) Error rate (error/bits).

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