An Interface between Several Cameras and Two Computers, using Differential Analog Transmission

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A system has been built to allow up to four scintillation cameras to be connected in parallel with two computers, yet provide for selection of individual pairs of camera/computer combinations with the exclusion of unwanted connections. Since the distances involved were relatively long, signal drivers were used to transmit the analog signals in a differential mode over multiple twin-paired lines rather than coaxial cable. By transmitting the signals differentially, any noise induced on the signal was subtracted at the receiver. The principal features of this system, which has been installed in two institutions, are described. A problem that occurred in connection with one camera is presented (also its solution), with a suggestion concerning parameters to be assessed at the time of system acceptance.

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The proliferation of computers in nuclear medicine departments has engendered many problems in the interfacing of these systems to scintillation cameras and, in some cases, in the transmission of signals over relatively long distances. Some nuclear medicine computers, such as the Digital Equipment Corporation's Gamma-11 with the old NC-11 interface, have only one input port for one scintillation camera, and thereby become exclusively dedicated to that particular imaging device—unless some form of hardware for signal equalization and camera selection is added to allow for more than one camera. Other systems, such as the Digital Equipment Corporation's Gamma-11 with the newer NCV-11 interface, have up to four input ports, and selection of the scintillation camera from which data are to be collected is controlled by software. In large nuclear medicine departments it is now quite common to have more than one computer, and it is desirable to have all the computers available as collection devices for all of the scintillation cameras, despite the fact that data may be acquired by only one computer from one of the cameras at any one time. Additionally, large departments often have satellite units elsewhere in the hospital, and it becomes necessary to transmit scintillation-camera data over relatively long distances.

Long-distance transmission of scintillation signals has been achieved by various methods. Dowsett and Roberts (*1*) and Elliott et al. (*2*) used line drivers and receivers to transmit analog signals from the scintillation camera over coaxial cables. Grant et al. (*3*) transmitted digital signals serially over coaxial cables. Santon, Prato, and Aspin (*4*) also transmitted digital signals, but did so over multiple twisted pairs in parallel.

Coaxial cables are expensive, and the transmission of digital signals implies duplication of the analog-to-digital converters at each scintillation-camera location.

Only in the case of the system described by Elliott et al. (*2*) was there any selection between cameras interfaced to the computer. In the other situations reported, the camera and computer formed an integral unit despite the geographic separation of the two units.

The method described here uses transmission of analog signals over multiple twisted pairs and includes a facility by which each of four cameras* may be exclusively attached to either of two computers.† The selection of which computer is to receive data is made at each camera location, and arbitration logic ensures that other cameras may not gain access once a particular camera/computer link has been established.

In general, the camera-to-computer cable connections are short (about 15–20 m), but in the case of one satellite imaging room the link is closer to 100 m. This distance, however, is still sufficiently short that the higher capacitance of twisted-pair cable over that of coaxial is offset by the decreased cost and ease of installation.

The major components of the system (Fig. 1) are the camera stations or switch boxes for selection of the receiving computer; an analog signal-transmission and reconstitution network using a multiple twisted-pair cable for the X,Y, and Z signals; and arbitration logic to ensure security of a camera-to-computer link once it has been established.

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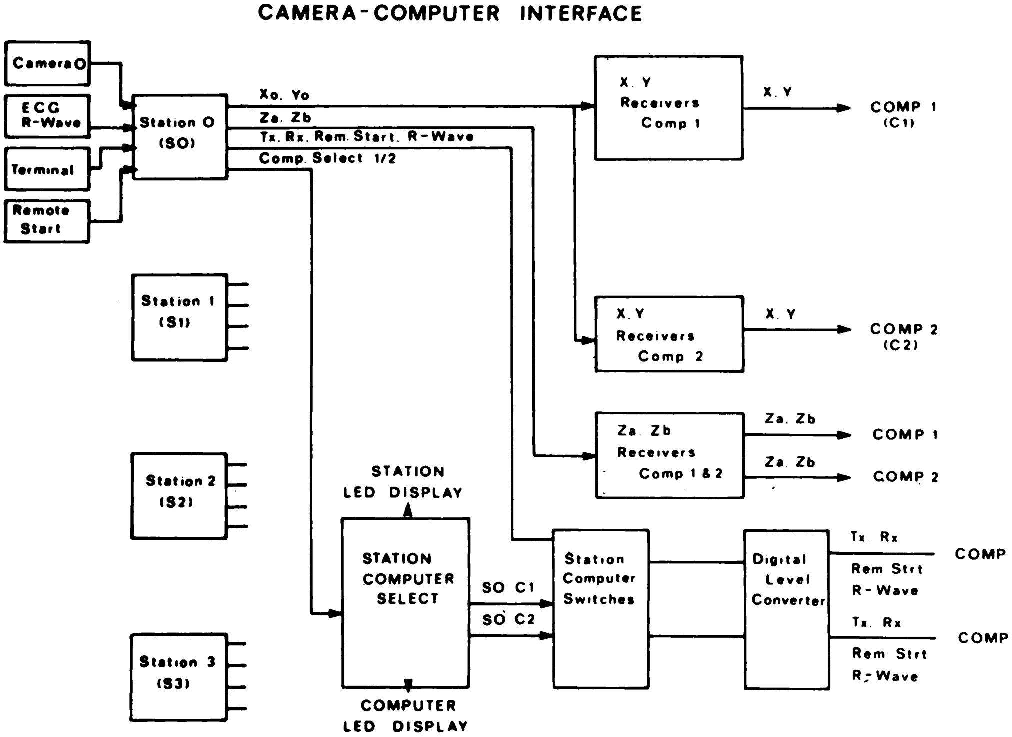

FIG. 1. Overall block diagram of system. Camera stations S1, S2, and S3 are identical to station S0. Camera data (Xo, Yo, Za, and Zb) are transmitted to both computer inputs (COMP1 and COMP2) at all times; only digital signals (Tx, Rx, Rem Strt, and R wave) are subject to selection and switching. Camera stations are located at scintillation cameras. Other modules are in a rack-mounted box in computer room.

TECHNICAL DESCRIPTION

Figure 1 is a block diagram showing the configuration of the systems that have been installed. The switch box at each camera station (Fig. 2) has input facilities for the X/Y position and Z energy signals, an ECG synchronizing signal (TTL logic pulse synchronous with the ECG R wave), a computer terminal‡ (which may be either 20 mA current loop or EIA), and a remote start signal (a TTL logical ground on switch closure). The other modules shown in Fig. 1 are contained in a rack-mounted box in the computer room.

FIG. 2. Each camera station has inputs for X/Y and Z signals from its associated scintillation camera. Front panel also has inputs for the gating signal and a remote start signal. Video terminal connects to back of unit, as does the multiple-twisted-pair cable that connects to receiver in computer room.

The switches at each camera station allow the operator to select one of the two computers for data input, and one of two attenuation levels for the X/Y position signals. The latter facility provides for zoom capability in excess of that provided within the computer interface under software control (*5*). Each camera station's switch box has a set of LED lights that indicate which (if any) camera-to-computer link is activated at that moment. This LED display is enunciated from the station's computer-select module in the computer room. A similar LED display is located on the front panel of the computer rack so that an operator in the computer room can also quickly identify which camera/computer combinations have been activated. If an attempt is made to activate a link with a computer that has already been selected from another camera station, the arbitration logic in the station's computer-select module prevents the second link from overriding the first.

In order to accommodate scintillation cameras of different manufacture and design, it was also necessary to incorporate a switch that allows selection between not only the normally separate Za and Zb dual-nuclide signals but also a Za + Zb composite signal. The NCV-11 interface normally expects separate Za and Zb signals, and the switch at the camera station has the function of separating a composite Za + Zb signal into two independent ones.

Each camera station is identical to the others so that, in the event of a failure, interchange or replacement is easily accomplished. Each camera station can also feed into both computers so that, in the event of a computer failure, data can still be collected from any of the cameras by the remaining computer.

Each of the signals is transmitted to the computer room through one pair of a multiple-twisted-pair cable.¶ At the computer rack the scintillation camera signals are reconstituted by the signal receivers (Figs. 1 and 4) and fed in parallel to both computer interfaces. The station's computer-select module (Fig. 1) acts as an arbitration unit under the control of the camera station, and sets the semiconductor switches in the station's computer-switch module, which routes all of the digital signals to the chosen computer via a digital-level converter. Thus, only the remote start, ECG gate, and remote-terminal transmit (Tx) and receive (Rx) lines are subject to switching. This implies that all scintillation-camera signals are available at both computer inputs and may be monitored there under software control from the system's console or analysis terminal. The camera input port is selected by software at the remote terminal. This situation does carry with it an inherent source of possible error. If an incorrect selection is entered at the time of acquisition, data will be acquired from a camera other than the one intended.

ANALOG SIGNAL TRANSMISSION

Primarily because of the distances involved, it was deemed desirable to transmit the data over multiple-twisted-pair cables rather than more expensive coaxial cables. This mode of transmission required that signal drivers and receivers be incorporated and that some mechanism be used to minimize the effects of noise pickup. We elected to transmit the signal over one line of a twisted pair, leaving the other line grounded. Any high-frequency noise picked up on the signal line could be assumed to be induced on the ground side of the same pair. The signals were therefore treated differentially at the receivers, and the induced noise thereby subtracted out (Fig. 3). Full differential drivers were not used because they would have been more costly and would have increased the density of the printed-circuit board considerably. Bench tests in the laboratory revealed that the differential receivers that were used exhibit sufficient noise rejection of the common-mode type (typically a ratio of 0.015) to be acceptable under these conditions.

The integrated circuits used were identical to those adopted by Spiers et al. (Personal communication), who had used them for direct analog signal transmission over coaxial lines. The major difficulty to be overcome was the determination of the appropriate terminating resistors for each stage of the transmission process. Figure 4 indicates the final values, determined empirically. Ideally, one would expect these values to match the characteristic impedance Rc of the cable. The signal drivers, however, lacked sufficient power to drive into the characteristic impedances, and unacceptable attenuation of the signal resulted. The values finally chosen provide optimum results in terms of signal amplitude, maximum noise elimination, and minimal high-frequency reflections.

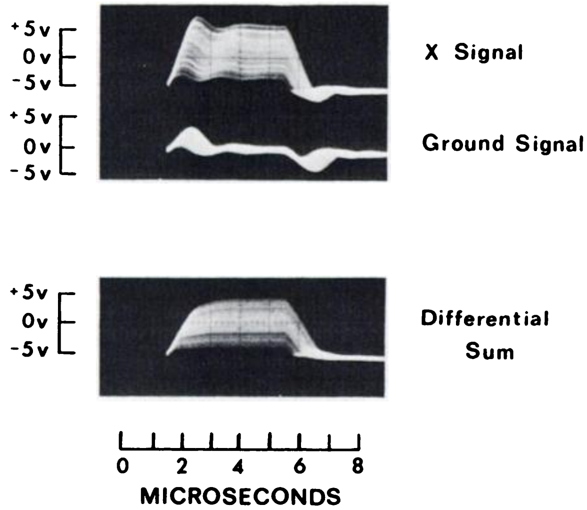

FIG. 3. Noise and ringing, induced on the line carrying signal, was also found to exist on corresponding ground line (upper frame). By subtracting signals one from the other, effects of induced noise were eliminated (lower frame).

The cable lengths indicated in Fig. 4 are nominal only. From scintillation cameras to camera stations they are all of the order of 7.5–10 m maximum. The camera stations are located at varying distances from the computer, the shortest being ~12 and the longest ~100 m. The final cable length from the receivers to the two computers has a minimum length of ~5 m and a maximum of 12 m, depending on the proximity of the two computers in each of the installations. Despite these relatively wide variations in cable length, the terminating resistors were chosen to be the same for each camera and each computer; this established a standardized situation, thereby permitting interchange of the camera stations should that become necessary.

ACCEPTANCE TESTING

The importance of acceptance testing and quality control of computer hardware and software is being emphasized in many quarters (*6,7*). The interface described here was subject to the normal flood-field and bar-phantom quality-control procedures to establish that the images were not subject to degradation during the transmission process. Nevertheless, one problem did elude initial detection.

One scintillation camera embodies a "universal computer interface," the purpose of which is to increase the amplitude of the camera's signals and ensure compatibility with the more common computer input requirements.

With this camera a problem arose that first manifested itself during a first-pass study of the heart. A dose of 20 mCi (740 MBq) was injected into the patient and data were collected by the computer using a framing rate of 2/sec. When the data were reviewed it was observed that, as the activity entered the field of view and the count rate increased, the image drifted down and to the right. Subsequently, as the activity entered the systemic circulation and the count rate decreased a little and stabilized, the image drifted back to its original position.

Checks using flood studies with this camera and simulated first-pass studies with the other scintillation cameras in the department failed to replicate the problem. The phenomenon could be duplicated using the same camera with either of the two computers by placing a small (3000 cps) source in a fixed position and moving a higher-intensity source into, across, and out of the field of view. This produced a sharp increase in count rate, which reached a high plateau and subsequently fell sharply as the source left the field of view. The drift in position of the "fixed" source was evident at an increased count rate as low as 6000 cps.

The problem was isolated to one involving that particular scintillation camera in conjunction with the signal-transmission system. The cause was a combination of isolated ground outputs on the camera's universal computer interface and the open-ended operational amplifiers of the camera-station signal drivers (Fig. 4). This implies that the ground connections indicated at the scintillation camera in Fig. 4 did not really exist. The reason for the isolated ground outputs remains doubtful, but it is assumed that it was an attempt by the camera manufacturer to avoid common ground-loop problems often associated with camera-to-computer interfaces. The input to the signal drivers is differential, but with no return connection, the X/Y signals would seek a path via a ground through the resistor R2 (Fig. 4), thereby causing a DC offset of the baseline voltage. The problem was resolved by grounding the output terminals on the universal computer interface of the camera, thereby providing a return path for the X/Y signals.

This problem serves to emphasize the need for quality control

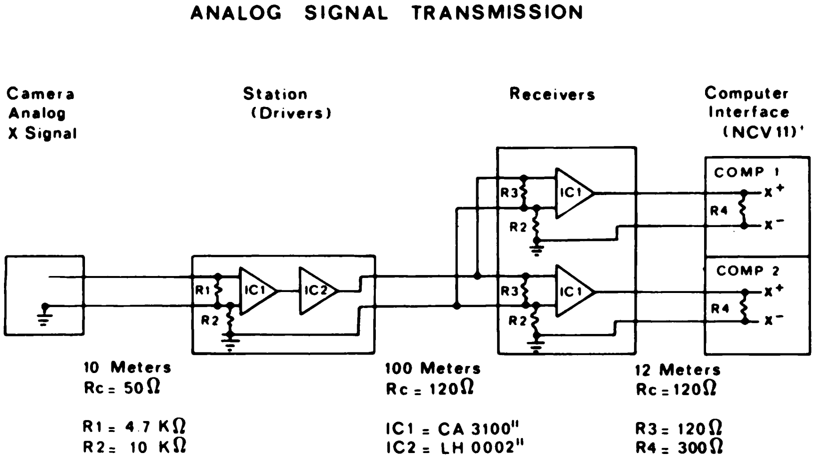

FIG. 4. Operational amplifiers[‖] are used as input devices at camera stations, and these drive signals to receivers that take the difference of the signals on the two lines, thereby minimizing effects of high-frequency noise induced in the transmission process. Terminating resistors indicated in this schematic were determined experimentally. Nominal lengths and characteristic impedances (Rc) of cables used for each portion of transmission system are indicated.

or acceptance tests that are specific to the camera/computer interfaces. Flood images and resolution checks made at stable count rates similar to those used during camera or computer installation and calibration failed to demonstrate the phenomenon described because at high count rates the baseline stabilized after a short time. Only simulated first-pass studies (changing count rates) demonstrated this particular problem. In addition to the normal acceptance testing procedures, we advocate that users of camera-to-computer systems should also perform a test to indicate if any shifts of the image take place when the count rate is rapidly changed.

CONCLUSION

We have described switching and signal-transmission system that allows up to four scintillation cameras to be interfaced to two computers. The system acts in such a manner that any two of four cameras may be connected separately to the two computers, with the remaining two cameras temporarily locked out. A high degree of flexibility is obtained because any of the four cameras may feed into either of the two computers, thereby making use of the specialized hardware or software available on each of the two systems.

In order to accommodate some relatively long transmission distances, signal drivers and receivers were used to transmit the scintillation camera's analog signals over multiple-twisted-pair lines in a differential mode to reduce the effects of induced noise.

Only the digital signals from the remote video terminals, the ECG gate signal, and the remote start signal are actually switched in the selection of a particular camera/computer combination. The scintillation camera's X/Y and Z signals are presented to both computer inputs from all cameras at all times.

The use of multiple-twisted-pair cable considerably reduced the cost of both the cable and its installation, and by transmitting analog signals it avoided the need for additional analog-to-digital converters.

This system has been used successfully in two institutions (since September 1980 in one case). One of these institutions has a scintillation camera located at a considerable distance from the computers. In one installation, three cameras are interfaced to two computers, and in the other case a full complement of four cameras are connected to two computers.

FOOTNOTES

Circuit schematics can be made available at cost by writing to Mr. E. Gauci, Computing Center, University of Western Ontario, London, Ontario.

[*] Various, including: G. E. Maxicamera 2, Picker 3C, Picker 4/15, Picker Dyna-Mo, Searle LFOV, Searle Pho/Gamma V, and Searle Pho/Gamma IV.

[†] Digital Equipment Corp.; Gamma-11 with NCV-11 interface.

[‡] Digital Equipment Corp.; VT52 or VT100.

[¶] Beldon Corp.; Type 8776, 15 pair twisted, individually shielded.

[‖] National Semiconductor Corp.

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