LONG-DISTANCE TRANSMISSION OF ANALOG GAMMA CAMERA SIGNALS

David J. Dowsett and Keith Roberts

University College Hospital, London, England

A system for transmitting gamma camera analog coordinate information over long distances to a computer center using coaxial cable links is described. The methods used for minimizing signal loss and reducing noise artifacts are outlined together with a description of the interface, which receives and corrects the transmitted signals prior to digitizing.

INTRODUCTION

Digitizing analog coordinate information from gamma cameras for subsequent computer analysis presents problems when the on-line computer is remotely situated from the camera source.

Three main systems for the transmission of this data exist: analog, digital, and video.

Each analog coordinate signal from the camera, as an X, Y, or Z pedestal voltage, can be transmitted by coaxial cable to the computer site where they are digitized by precision analog-to-digital converters (ADCs). This is the more usual form of transmission over short distances; however, compensation for signal losses must be made for longer cable lengths (*1*).

Alternatively the analog signals can be digitized locally and the X and Y coordinate information transmitted as a parallel bit stream over multiconductor cable to the computer. Difficulties with parallel digital transmission of nuclear medicine data over long lengths of multiway cable have been experienced however (*2*). Video transmission of on-line gamma camera images over long cable lengths has been described (*3*) and suggestions have been made for bridging large distances between gamma cameras and computers by using an off-line portable video recorder (*4*), or digital tape recorder (*5*).

In spite of these alternatives, analog transmission of coordinate pedestal voltages for static and dynamic studies still has many notable advantages in terms

Received Mar. 12, 1974; original accepted May 10, 1974.

For reprints contact: David J. Dowsett, University College Hospital Physics Dept., First Floor, Shropshire House, Capper St., London WC1, England.

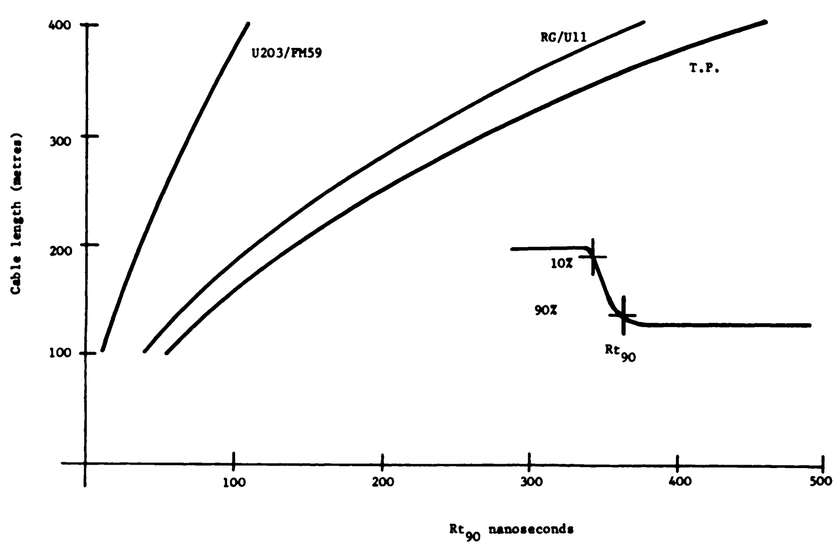

FIG. 1. Plot of three cable time constants for various cable lengths up to 400 meters. High-quality cable (U203/FM59), together with average-quality (RGU/11) and a twisted pair (TP) are compared. Time constant is measured as 90% point of risetime and expressed as nanoseconds on "X" axis.

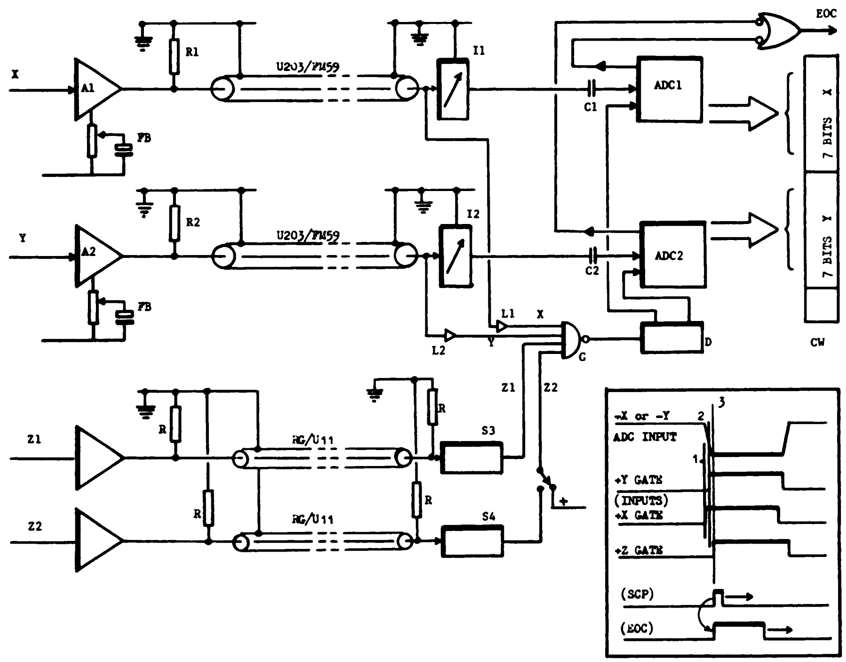

FIG. 2. Block diagram of transmitting and receiving components of gamma camera interface, described in text. Coordinate amplifiers A1 and A2 drive X and Y signals over U203/FM59 cables, terminated by R1 and R2 proximally and I1 and I2 distally. Z1 and Z2 signals are carried by RG/U11 cables and received by S3 and S4. Signal Z2 is shown unused. Pulse sequence shows —X and —Y ADC inputs which are also used for driving gate "G" through L1 and L2 TTL level converters. Arrival delays seen between +X and +Y signals at "G" input are shown by lines 1 and 2; line 3 represents +Z signal. These gated signals produce "start-conversion pulse" (SCP) at output of variable delay "D," which controls positioning of "end-of-conversion" (EOC) signal on —X and —Y inputs. ADCs each provide 7-bit output for constructing final computer word (CW).

of cost and simplicity. It also provides a method for displaying the real-time image data at the computer site using an X, Y display oscilloscope, a very useful facility, particularly when collecting in list mode.

It is the purpose of this communication to describe the techniques successfully employed for transmitting analog gamma camera signals over cable lengths of 450 meters (approx 1450 ft).

METHODS AND MATERIALS

As the cable route at this hospital was tortuous, a flexible, high-quality, low-loss coaxial cable (Type U203/FM59) was chosen for carrying the 5-μsec X and Y coordinate signals from the camera to the computer site. The low resistance of this cable (2 ohms/100 meters) is essential to reduce signal loss, a serious problem with increasing cable length, as induced noise from external sources and the intrinsic noise of the cable's voltage-standing-wave ratio (VSWR) lowers the signal-to-noise ratio and degrades the coordinate information so affecting transmitted spatial accuracy of the image. The time constant of the cable is also small, achieved by having a small cable capacitance (5600 pf/100 meters; 17 pf/ft).

Each end of the coaxial cable screening was carefully grounded and multipoint shield grounding was also adopted.

Two average-quality coaxial cables (RG/U11) carry the fixed amplitude Z pulses. Analog variations in the Z signals can be collected by using the high-quality X and Y cables; the computer can then provide an isotope energy spectrum display for accurate PHA window adjustment. Operator control signals from the camera are carried by a twisted pair single-core cable.

The graphs in Fig. 1 plot the time constants for the three cable types used here. The U203/FM59 time constant contributes far less risetime distortion whereas the average-quality coaxial cable (RG/U11), in lengths greater than 100 meters degrades pulse risetime excessively. A twisted pair cable (TP) is included in the graph for reference.

The additional risetime, due to the cable's time constant, should not encroach too far into the existing plateau region of the pedestal as sufficient width must remain in order that the best section of the plateau can be selected for digitizing by the ADCs. The converters used are successive approximation DATEL type N series with 12-bit resolution and a 3.6-μsec measured encoding time. The added 100-nsec risetime given to the X and Y pulses by the time constant of the U203 cable over its 400-meter length, as seen in Fig. 1, increases the existing pulse risetime by a third to 400 nsec. However, sufficient pulse-width remains for digitizing without resorting to sample and hold techniques.

Figure 2 is a block diagram of the gamma camera's cable drivers together with the receiving sections of the computer interface.

The U203/FM59 cables are driven by single-ended transistor amplifiers (A1 and A2) which use BD124 power transistors with variable emitter feedback, (FB), which can be adjusted for optimum pulse geometry. The collector load resistances (R1 and R2) supply the proximal end 75-ohm terminations of the cables. The distal end terminations consist of constant impedance 75-ohm attenuation networks (I1 and I2) which receive the large transmitted signal voltages (15 volts maximum) and reduce them to within the 5-volt range of the ADCs. Overall attenuation of amplified coordinate signals in this way provides good signal-to-noise ratios. Capacitive coupling (C1 and C2) at the inputs to each ADC removes low-frequency cable VSWR noise and AC interference; a variable offset at the ADC input (not shown) restores ground reference. The combined effect of large signal transmission voltages and capacitive coupling at the ADC input reduces the noise component in this case to −54 db.

It is also important to eliminate large noise spikes on the Z signal cables as these will trigger false conversion cycles in the ADCs. Z signals are therefore transmitted as 25-volt fixed amplitude pulses which are clipped and shaped at the receiving end (S3, S4) to within the TTL +5-volt range. Induced noise spikes now fall below the TTL threshold voltage and are missed.

As the original signal coincidence is lost to some extent due to differing transmission delays in the cables, it is regained by gating all four signals (X, Y, Z1, Z2) at the interface and using the output signal from the gate (G) for initiating the analog-to-digital conversion cycle. The Z2 signal can be switched out for single-isotope studies. The output signal (SCP) from this gate has a variable delay (D) so that optimum plateau regions of the X and Y pedestals can be selected for digitizing as mentioned before. Line receivers (L1 and L2, National Semiconductor 8820) convert the X and Y signal voltages to TTL levels for driving the gate. The end-of-conversion (EOC) signal from both ADCs is OR'ed and this signal provides logic control for other parts of the interface.

The 12-bit digitized X and Y voltages are stripped to 7 bits and combined with a 2-bit code to form a 16-bit computer (PDP11/45) word (CW). This coordinate digital information together with internally generated timing words queue in a derandomization buffer (Fairchild FIFO 3341) which feeds a PDP11 direct memory-access universal interface (Digital Equipment Corp. DR11B).

RESULTS

The influence of noise on the positional accuracy of the gamma camera events was tested by sending slow fixed amplitude pulses from a pulse generator through both amplifiers driving the X and Y cables and collecting these pulses over a period of about 6 min. All the digitized voltages collected by the interface were identical showing that baseline noise was unlikely to influence positional accuracy of camera events over usual data collection periods.

The dimensions of a digitized standard image were measured over a period of several weeks; as no discernible change in image size was found the overall stability of the drive amplifiers and interface were accepted.

Operator communication between camera and computer during clinical data collection is at present achieved by using a combination of telephone direct link and push-button control signals.

DISCUSSION

Providing care is taken when selecting coaxial cables for linking camera to interface, analog coordinate signals can be transmitted both economically and accurately over relatively long distances. In the case described, flexible cables were the only practical answer but straight connections over longer distances would be better attempted using a semirigid air-cored coaxial conductor, with a much smaller time constant.

Errors introduced into the system by quantizing the analog voltage are influenced by both intrinsic and extrinsic sources. Differential nonlinearity of successive approximation ADCs is perhaps the main culprit for introducing intrinsic quantizing errors. This can be improved by shortening the converter word length (*6*).

Most extrinsic quantizing errors are introduced by either noise, sloping pedestal plateaus or distortion of pulse geometry. Noise, which causes an unstable baseline, must be reduced to insignificant proportions if spatial accuracy of the transmitted camera image is to be maintained. Changes in voltage caused by plateau slope will lead to gross distortions in the spatial information carried by the coordinate signals. If the input voltage slope during the bit-encoding-time of the ADC (333 nsec) is equal in magnitude to the least significant bit (approx 40 mV in this case), then instead of a linearly diminishing digital output for a series of regularly diminishing voltages at the ADC input, an irregular rise and fall in the digital output will be seen together with gaps where some codes have been missed entirely. This process gives a banded pattern to the computer-reconstructed gamma camera image. Less severe plateau slopes will of course reduce this effect. If pulses with poor geometry are offered by the gamma camera itself, then "sample and hold" modules should be located at the receiving end of the cable.

CONCLUSION

The problem of linking a gamma camera to a computer for on-line collection of clinical data is best solved by transmitting the analog pedestal coordinate information over high-quality, low-loss coaxial cable. The data can also provide a real-time visual display of the camera image for monitoring while being accepted by the computer interface.

Good pedestal geometry is maintained over long distances by careful termination at both ends of the cable and large signal-to-noise ratios achieved by attenuating the amplified signals by 3:1 or more at the receiving end. Recent improvements in the speed performance of commercial ADCs allow real-time digitizing of fast pedestal voltages to be achieved comfortably even with the decreased pedestal pulsewidths due to cable time constants.

ACKNOWLEDGMENTS

The authors wish to thank John S. Clifton and Andrew Todd-Pokropek for their support and valuable advice; David Ingram for developing the computer software; Demetri Hatziandreou, David Lane-Wright, and Terry Mitchell for engineering assistance, and Sandra Winyard for her expert appraisal of the manuscript. Department of Health and Social Security Grant A/C334/BG4/3.

REFERENCES

1. Smith AH, Barker MCJ: The on-line application of a small digital computer to a gamma scintillation camera. *Phys Med Biol* 15: 503–516, 1970

2. Dowsett DJ, Ritchie D: An off-line computer interface for a rectilinear scanner. *Phys Med Biol* 16: 249–256, 1971

3. Ashburn WL, Harbert JC, Whitehouse WC, et al: A video system for recording dynamic radioisotope studies with an Anger scintillation camera. *J Nucl Med* 9: 554–561, 1968

4. Kellam RO, Jones GR, Ashburn WL: Independent operation of a commercial digital tape recorder originally designed as an integral scintillation camera accessory unit. *J Nucl Med* 14: 699–701, 1973

5. Vernon P, Glass HI: An off-line digital system for use with a gamma camera. *Phys Med Biol* 16: 405–415, 1971

6. Cox JR, Hill RL: Design considerations for interfacing computers to gamma ray cameras. In *Quantitative Organ Visualization in Nuclear Medicine*, DJ Kenny, EM Smith, eds, Miami, Fla, University of Miami Press, 1971, pp 465–489