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TOP SECRET

HANDLE VIA
BYEMAN
CONTROL SYSTEM

(S) NATIONAL RECONNAISSANCE OFFICE
WASHINGTON, D.C.

THE NRO STAFF

11 March 1968

see change on page 2 of attachment.

MEMORANDUM FOR MR. DONELSON

SUBJECT: Indications/Warning Information

In his 26 February message to you answering a previous question, LtCol Bonner suggested that you might find helpful some papers he had prepared on the factors affecting performance of readout type image forming reconnaissance systems. The papers he referred to are attached for your information and retention.

EDWIN F. SWEENEY
Colonel, USAF

Attachments

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CONTROL NO BYE-12711-68
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24 January 1968

SUBJECT: Capability of Readout Systems to Respond to Warning/Indicator Requirements

1. Data Input

a. Before discussing the characteristics of various classes of photographic readout systems, it is necessary to understand a fundamental parameter common to all classes of readout systems; input data rate. This parameter is expressed by the following formula:

$$f = \frac{w\,n\,v}{r^2}$$

Where:

f. is the input data rate in resolution elements/sec, which is equal to video bandwidth in cycles/sec when the elements are read out in series. In photographic terms, f is the signal frequency corresponding to the limiting ground resolution.

w is the ground format width in feet.

v is the satellite velocity in ft/sec.

r is the limiting ground resolution in ft. (Note: Limiting resolution is always less than nominal resolution.)

n is number of readout scan lines per resolution element, or number of samples per resolution element. (Note: n must be greater than 2 to preserve equal resolution in both directions. A typical value of n for a high quality system is 4.)

b. Let us consider a typical case for the Warning/Indicator mission where a nominal resolution of 2.5 ft is desired against a set of targets of 2 mi. diameter. Studies indicate that under these circumstances a format width of the order of 4.25 miles (nadir) is

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required and the limiting resolution of the sensor (referred to the ground) is of order 1.8 ft. Under these circumstances, at altitudes of interest (150 - 300 miles) the input data rate f to the readout system is about 800 X 10^6 resolution elements per second.

c. There are a number of ways in which data input can be characterized. Perhaps the most convenient manner for a readout system is in terms of camera badwidth (frequency) since this parameter allows a direct derivation of the camera output frequencies and times required to read out the information.

d. Camera bandwidth is the highest meaningful frequency in the camera ground scene image. It is equal to the data input rate f and is therefore based on satellite velocity, ground format width, limiting ground resolution & number of readout scan lines per resolution element of the ground scene ~~limiting ground resolution, and number of readout scan lines per resolution element of the ground scene~~. Higher frequencies than this camera bandwidth frequency may be present in the ground scene, but these higher frequencies contain noise to such an extent that they reveal no information. The camera bandwidth frequency may be considered to be the upper frequency on any camera's output that would be fed into a data link for transmission back to the ground. Note: Camera bandwidth is not likely to be the same as the data link RF bandwidth. RF bandwidth is dependent upon signal power, noise-in-the-data-link power, and desired signal-to-noise ratio at the receiver end of the data link in addition to camera bandwidth.

2. Types of Readout Systems

a. Readout systems may be characterized by two fundamental sets of characteristics:

(1) Availability of on-board image storage in excess of the amount required for exposure. There are two basic types of systems currently possible (in a conceptual sense) which will be called [redacted] Systems and Delayed Readout Systems.

(2) The data return concept employed. Again, two basic types are possible; relay via other satellites to a ground station, or direct transmission to a ground station.

b. The types of readout systems will be described in the context of (1), above, with the applicability of data return concepts discussed for each type.

(1) [redacted] the data collected must be transmitted to the ground at the collection rate. For covert reconnaissance applications this requires one or more satellite relay stations, data links and ground recording systems capable of handling the peak camera bandwidth generated (of order 800 MHz).

(2) Delayed Readout Systems. Capabilities of delayed readout systems are much more flexible and consequently more complex to describe. There are two subdivisions of this class: a) cameras capable of storing only one frame at a time (vidicon cameras, etc.), and b) those which can store many frames (dielectric tape cameras, film cameras, thermoplastic tape cameras, etc.).

(a) Single frame storage cameras are similar in many respects to a [redacted] system with the exception that the output data rate does not have to be the same as the camera bandwidth (input data rate). The requirement here is that the product of readout time and camera output rate still equals the camera bandwidth so all of the input data gets read out. For example, a 4.25 mile square frame as described in para. 1b, above, contains about 8.3×10^8 cycles of information. This can be readout in about 16 sec with a 50 MHz bandwidth camera output rate, 8 sec with a 100 MHz camera output rate, 4 sec with a 200 MHz camera output rate, etc. For operational use of this camera, one or more relay satellites are also required since each frame must be read out before a new picture can be stored. Data link bandwidth requirements can be made much less severe than for the [redacted] camera but at the expense of peak frame rates and consequently the target "scores" possible.

(b) Multiple frame storage cameras provide the greatest flexibility in data return concepts of any of the types possible. These cameras can obviously operate in the same manner as the single frame camera previously discussed. In addition, photography can be stored for periods of many hours and then read out. Further, input frame rates are not directly dependent on camera output rate and data link RF bandwidth.

3. Let us consider two specific examples of multiple frame storage camera performance taken from the studies which produced the target coverage which is presented elsewhere. Consider a single satellite which, operating against the combined Warning/Indicator and

surveillance deck, collects up to 830 miles of photography on its peak rev and an average of 3200 miles/day. Assuming a fixed bandwidth data link available and, therefore, a fixed camera output rate, one can then calculate the readout time required. By comparing the readout time required to the readout times available for various data return concepts, one can calculate the proportion of the data collected which can be returned in the time available and also the associated time lags between collection and receipt.

a. As a first example, if one desires to retrieve the information collected within less than one orbital period, the data return system must be sized to handle the collection of the peak rev. This obviously requires one or more relay satellites simply because of orbital geometry. In the case studied, 1.6×10^{11} cycles of information are collected and with a 150 MHz camera output rate a minimum of 18 minutes of readout time per rev is required. Conversely, assuming a single relay satellite will provide at least 40 minutes of readout time per rev, one concludes that a data link to handle a 67 MHz camera output rate is enough for this concept.

b. As a second example, assume readout direct from satellite to a single CONUS ground station at 40°N latitude. One finds that the total readout time available per day is about 14 minutes. 3200 miles/day corresponds to 6.2×10^{11} cycles of information. The camera output rate required is about 740 MHz to read the entire take-out. Conversely, if 150 MHz camera output rate is available, only 648 miles/day can be returned. In either case, time delays of up to 10 hours will be incurred in data receipts due to the geometry of the orbit.

4. There are many other data return concepts possible which life between the two extremes presented in terms of camera output rates required and return time. For instance, another possibility is to relay to two ground stations in CONUS, separated in longitude by an appropriate distance to give independent coverage. Selection of a concept best for a particular system depends on a trade-off between system costs and operational requirements.

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24 January 1968

SUBJECT: Readout Data Return Concepts

1. Comparative evaluation of various data return concepts for an electronic storage camera is a complex problem because of the many interrelated factors which affect it. The user is concerned with four factors: quality, quantity, timeliness and cost of the photo data returned.

2. Fundamental Relationships

2.1 Let us first consider the question of input quantity. For work with satellite readout systems, it is convenient to speak of a data quantity collection rate in terms of megacycles/mile. The appropriate formula for rough calculations is:

$$qi' \left(\frac{\text{megacycles}}{\text{mile}}\right) = 36.97 \frac{f\,n}{r^2} \qquad (2.1.1)$$

Where:

qi' is information collected per linear ground mile of imagery. (Note: The units are spatial frequency not MHz/mi.)

f is ground format width in miles at nadir.

n is number of scan lines per resolution element. (We will use $n = 4$.)

r is limiting ground resolution of the system in feet.

Note that qi' is wholly a function of the sensor subsystem design. If one assumes that there is a strong desire to preserve all the quality of the sensor through the data link-ground recorder elements, the question of photo quality enters the problem only through this relationship. Note also that photo quality is inversely proportional to r and qi', thus increases as the square of quality.

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2.2 Having defined the collection rate, it is easy to define the total amount of information collected in any period of time, (qi) as:

$$qi = q\acute{i}\ m \qquad (2.2.1)$$

Where:

m is the number of linear miles of photography taken.

2.3 Having defined the amount of information collected in some period of time, one can now define the fundamental relationship which governs the data return system:

$$\frac{qi}{tb} = 1 \qquad (2.3.1)$$

Where:

t is the readout time in seconds.

b is the maximum information bandwidth of the data link (or ground recorder) in MHz/sec.

2.3.1 Let us make the appropriate substitutions in (2.3.1) from (2.1.1) and 2.2.1) and convert to commonly used engineering units. One then arrives at:

$$\frac{f\,n\,m}{r^2\,b\,t} = 1.62 \qquad (2.3.1.1)$$

Where the units of the variables are:

f - nautical miles

n - dimensionless

m - nautical miles

r - feet

b - MHz

t - minutes

Using this relationship, one can examine all major trades in system parameters. If one is interested only in the data return problem (e.g., assumes f, n and r fixed), the relationship is more conveniently written as:

$$\frac{q\acute{i}\ m}{b\ t} = 60 \qquad (2.3.1.2)$$

3. Trade-Off Relationship Between m, b and t. There are three ways to look at the trade-offs possible. These are: a) Assuming b and t fixed, what is the maximum value of m possible?; b) For fixed m and t, what value of b is required?; and c) For fixed m and b, what value of t is required?

3.1 Having derived the necessary math model (2.3.1) let us consider the numbers associated with a specific value of $q\acute{i}$ derived from the recent studies for an Indicator/Warning System design:

f - 4.25 mi

n - 4.0

r - 1.8 ft

$\therefore q\acute{i}$ = 194.0 megacycles/mi

(Note that the subsequent calculations assume a 100% scan efficiency; e.g., if a strip of photography m miles long is to be scanned out there is no dead time such as retrace times or gaps between frames involved. If a particular system design has such times, appropriate adjustments must be made. For example, the current CBS camera design has a 94% scan efficiency which implies that for this system the numbers for b, t, or m must be changed by 6% depending on the trade being examined.)

3.2 Based on $q\acute{i}$ of 194 megacycles/mi, one gets the following relationship:

$$m = 0.309\ b\ t \qquad (3.2.1)$$

This is plotted in fig. 3.1 as m vs. t for values of b ranging from 5 to 600 MHz.

3.3 Let us now consider some illustrative cases of questions a) - c) of paragraph 3, above. These cases are taken from the work done in connection with the Warning/Indicator System studies; a) Given b = 150 and t = 40/min/day, how many miles of photography can be returned/day? The answer from figure 3.1 is 1800 miles/day.; b) Given m = 5000 miles and t - 150 min/day, what value of b is required? From figure 3.1 we see the b is about 100 MHz.; c) For m = 1000 miles/day and b = 300, how much readout time is required per day? Again, from figure 3.1 one finds t = 11 min/day.

4. <u>Timeliness and Cost</u>. The remaining factors bearing on the data return problem as identified in paragraph 1 are timeliness and cost. We will not discuss cost in this paper. The issue of timeliness is very complex because one must consider orbital mechanics and their relation to geography in addition to the factors already considered. There are no simple mathematical models which one can use at this stage. Particular concepts must be addressed on a case-by-case basis, and for most concepts a description of the time lags between collection and receipt for one particular situation is a complex problem in itself. Thus, one is led to the use of generalizations, averages and approximations which can be misleading. With these reservations in mind, let us look at four particular cases.

4.1 <u>Readout Via a Data Link Relay Satellite</u>. This case is the simplest of the concepts considered to discuss. In this concept, we assume a single synchronous relay satellite placed so as to have continuous access to a CONUS ground station.

4.1.1 It is evident that such a satellite will have access to a low altitude photo satellite at every rev for at <u>least</u> half of its orbital period. [redacted]

4.1.2 If one assumes that the photographs collected on each photo rev are completely read out prior to the next rev, this implies (for photos taken over the Sino-Soviet area) that the maximum time delay is about 3/4 of a rev or less than 70 minutes, and the average time delay is less than 35 minutes.

4.1.3 Next, let us calculate the number of miles of photography which could be returned per rev and per day assuming a 150 MHz data link capability using the relationship derived in paragraph 3. One gets (based on 7 photo revs/day):

miles/rev = 4,175

miles/day = 29,226

These numbers, of course, do not imply that the system could be used in such a way but only that the time available for data transmission is large and that the capability of data link of such bandwidth is very high. The system would actually be constrained by the power budget, the storage capacity, the targeting philosophy and wear-out of the system.

4.2 Next, let us consider the general case of a photo satellite reading out direct to one or more ground stations. In this case, the average readout time/day is a function of satellite altitude and ground station latitude. Time lags are a function of the above and also orbital phasing of the satellites and ground station longitude. With the possible exception of a ground station located above 75° North Latitude (or South Latitude), one cannot match readin and readout passes on a one-for-one basis and time lags are, in general, several orbital periods. Except for the case of orbits whose ground traces repeat daily, readout times and time lags vary from day to day. Further, since access times are much shorter than the relay satellite case, the quantity of data which can be returned is much less, or conversely the bandwidths required are much higher.

4.2.1 First, let us consider a ground station above 75°N. (Thule, for example.) This is the most favorable region to put a ground station from the standpoint of quantity of data and also timeliness (insofar as receipt at that location is concerned). For the orbits studied, the following figures were derived:

System	Average Readout Time Per Day Per Satellite	Time Lag Average	Time Lag Maximum
[redacted]			

Note that these time lags were derived for a particular case. While they are thought to be typical, the maximum could be quite different for a different orbital listing than the one assumed.

4.2.1.1 For the average readout times above, let us calculate the amount of data which could be returned/day on the average using a 150 MHz data link. One finds:

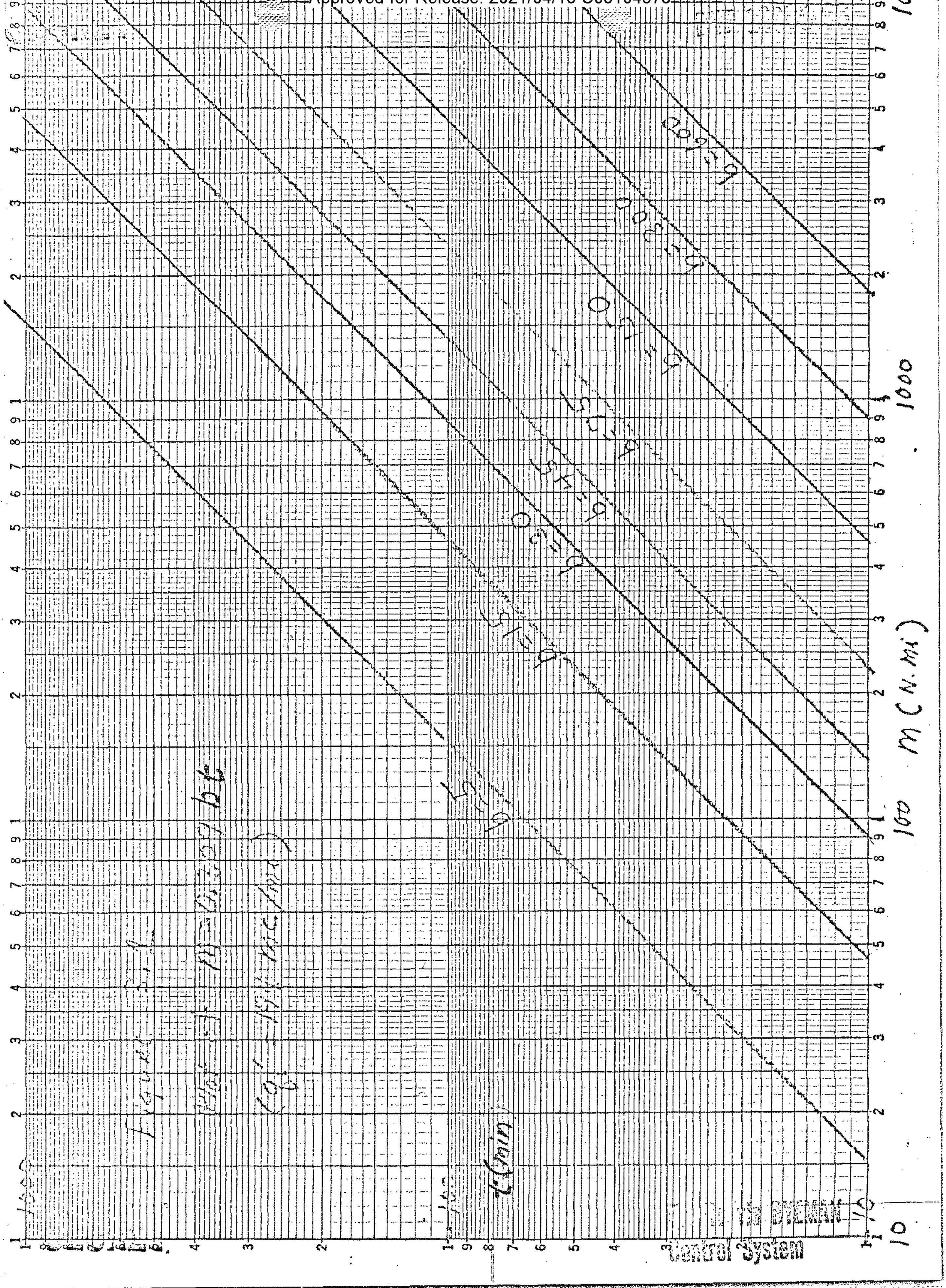
System	Miles/Day of Photography
[redacted]	

4.2.2 Next, let us consider a ground station near [redacted] for example). For the orbits studied one finds:

System	Average Readout Time Per Day Per Satellite	Time Lag Average	Time Lag Maximum
[redacted]			

4.2.2.1 With the readout times above and a 150 MHz data link, one finds the data return per day to be:

System	Miles/Day of Photography
[redacted]	



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WHIG
FOR: MAJ J REGENHARDT
REF: BYE (16605-68, 29 JAN 68)
SUBJ: ERROR IN SP-6 LETTER, WARNING/INDICATOR REPORT
1. ATTACHMENT ONE OF REFERENCED LETTER HAS A TYPOGRAPHICAL ERROR IN SECOND SENTENCE OF PARA 1D. SENTENCE SHOULD READ:
"IT IS EQUAL TO THE DATA INPUT RATE F AND IS THEREFORE BASED ON SATELLITE VELOCITY, GROUND FORMAT WIDTH, LIMITING GROUND RESOLUTION AND NUMBER OF READOUT SCAN LINES PER RESOLUTION ELEMENT OF THE GROUND SCENE."
2. PLEASE RELAY THIS CORRECTION TO ANY OTHER PARTIES THAT YOU HAVE FURNISHED COPIES OF ATCH ONE TO.
~~S E C R E T~~
BT

~~DJH~~

~~letter~~ TRIX - 0726
para 2 - 24 Jan 68
para 1 - data input.

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