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## GENERAL REVIEW OF MISSILE TELEMETRY

*by* DALE SAMUELSON
Sales Manager, Instrumentation Division
Applied Science Corporation of Princeton

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## AN ACCOUNT OF THE DISCOVERY OF JUPITER AS A RADIO SOURCE

*by* K. L. FRANKLIN, Associate Astronomer
American Museum—Hayden Planetarium

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# GENERAL REVIEW OF MISSILE TELEMETRY

*by* DALE SAMUELSON

Sales Manager, Instrumentation Division

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## 1. INTRODUCTION

In reading your morning paper it sometimes may appear that the only reason for firing a missile is just to see whether it will leave the pad or not. Very seldom is there any mention of what the engineers, who have spent many weeks, months and years in preparation for this moment are actually trying to determine.

So far in the history of American missile building, the only reason for firing has been generally to gather data to determine the actual operating characteristics of the missile as it is launched and moves on its directed course through space.

As you know, during a complete schedule of firings, the goal is to determine what happens to every component, structure, and section of the missile frame, its power plant, and the guidance system, computers and other electronic elements that go to make up the overall missile. The gathering of all this information, which in some cases may encompass hundreds of different pressures, temperatures, vibrations, stresses, strains and other physical and electrical phenomena, and the transmission of this composite of data, followed by its reconversion to a logical and usable form on the ground, is covered by the general phrase "missile telemetry."

In the complexity and great quantities of telemetry equipment required for such a firing, even the instrumentation engineer finds it difficult to keep in mind his prime purpose. This purpose is to provide to the missile design engineer in his laboratory back in the engineering department the new empirically determined facts and statistics he needs to carry on his assignment of producing as fully qualified missile as possible.

## 2. TELEMETRY HISTORY

Missile telemetry is an outgrowth of telemetry that was initially developed for piloted aircraft use. In the earliest days of flight testing of manned aircraft--those days when manned aircraft was in model T form--it was the job of the pilot to take notes of his instrument readings as he went through his predetermined tests. Later as the aircraft became more complex the pilot had a full time job just flying the airplane. Sometimes a second man went along to make notes on what was happening, and later a system of photo panels was introduced by which a movie camera was placed in the cockpit with the pilot to take photographs of the instrument panel readings. The system of photo panel is still used to some extent by small aircraft firms.

The introduction of the jet plane brought about requirements nearly as stringent as those found in today's missile.

## 3. NEED FOR TELEMETRY

Actually, today telemetry is used for two purposes. The prime one, of course, is to provide a complete documentation of the actions and reactions of a missile or aircraft under all flight conditions to aid in the efforts to either prove or improve its design and construction.

A second important use of telemetry in manned aircraft is to provide an increased level of safety for the pilot.

In the case of modern manned aircraft where the pilot does not have control over what may be going on in various parts of his plane, telemetry is used as a safety precaution. (Illustration #1.) This is something of a posed picture showing a man on the ground watching changes in the plane's parameters while the pilot puts it through its tests. On various monitor scopes and strip charts he is able to see what is happening to temperatures, pressures, stresses and strains that are taking place in the aircraft when the pilot puts the plans through maneuvers where these parameters are stretched to their maximum, and when the situation may be getting dangerous he can warn the pilot either by requesting

Illustration # 1

that he not put the plane through a certain maneuver again, or that the pilot return to the ground before he finds himself in a situation he cannot get out of. (Illustration #2.) Here is seen on a 17" scope what is happening in real time to 45 channels of information from a plane or missile.

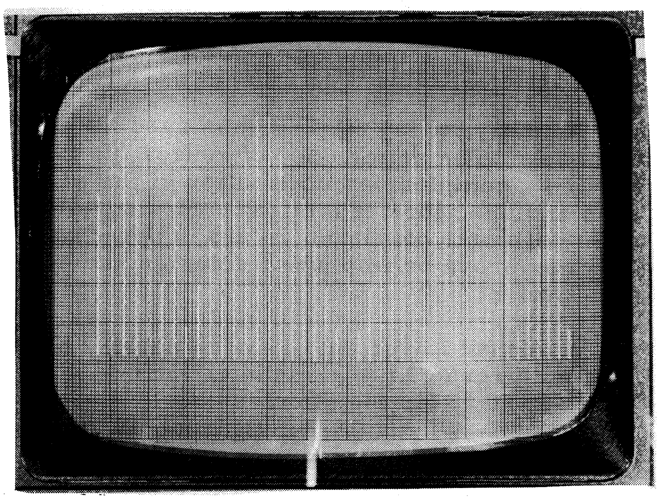


Illustration # 2

So, on the ground, while a flight is taking place, actual reduction of the information can be obtained. It is possible to actually follow the changes taking place in the missile during real flight time and simultaneously record the data for later play-back.

4. TELEMETRY STANDARDS

Shortly after World War II, when it became apparent that the only practical way of handling the data being gathered for a study from aircraft and missile flights, would be by transmitting it over a radio link, the Research Development Board set up basic standards for use of an FCC allocated frequency range from 216 to 235 mc. This board, in order to maintain some basic consistency within the industry, and based on a concensus of the industry at that time, developed a set of basic telemetry standards commonly known as RDB (Research Development Board). These standards still exist today although they are now under control of the IRIG or Inter-Range Instrumentation Group made up of the heads of flight test at the various flight test centers, such as Patrick Air Force Base, Holloman Air Force Base, Kirtland, White Sands, China Lake, Pt. Mugu, and the other missile and aircraft flight centers. They are now known as IRIG standards.

As a result, the development of telemetry equipment based on these standards has been held within fairly strict limits. Certainly there are many advantages to having such a standard set up for the industry. There also has been considerable criticism aimed at such standards because it can be argued that in some cases it actually has stifled new developments. The industry has lived with them and as a result there is a high degree of interchangeability and flexibility of the available equipment. Any airborne equipment built to these standards, for example, is compatible with ground based equipment at almost any U.S. flight test center.

Before we go further, however, we'll review some of the fundamentals of a telemetry system.

5. TRANSDUCERS

Before data can be transmitted or telemetered to the ground it must be "prepared" or converted to a standardized form which can be handled by the telemetry system. The general term used to describe these elements for the transformation is "pick-up" or "transducer." The standards of the industry have been designed so that the output of a transducer is a voltage ranging normally from 0 to 5 volts or between $\pm 2\ 1/2$ volts, representing, percentagewise, the range of the physical input to the transducer.

For example, the parameter being measured may be a pressure that has been predetermined to range somewhere from 0 to 100 pounds. The required transducer is an element that will convert proportionately the measured pressure to a voltage output ranging from 0 to 5 volts or from -2 1/2 to +2 1/2 volts. There are literally thousands of different types of pick-ups on the market today to handle every conceivable type of physical and electrical condition. Of each type there are units to handle many different ranges under various conditions. It is the job of the instrumentation engineer working on the missile to determine exactly which transducers on the market best fulfill his requirements.

As a result, all inputs to any type of telemetry set are voltages in a standard range, or at least are all adjusted up or down before any frequency mixing or coding takes place.

In addition to these "high level" transducers, those ranging generally in the voltage area from 0 to 5 volts, there are also many requirements for handling what is called low level data. This data is primarily from thermocouples for measuring temperatures and from strain gages where the outputs are in the microvolt and millivolt range, the maximum usual output voltage being around 15 to 50 millivolts. In the past it has been necessary to install an individual amplifier for each one of these low level probes or transducers, but systems are now becoming available which make it possible for them to be handled as low level data directly.

Now let us take a look at the basic standards set up for the most commonly used telemetry system--the FM/FM system which basically is a frequency division system, a method of FM modulating an FM carrier. (Illustration #3.) First, here are the basic RF carrier and Modulation Standards as set up for the telemetry links.

**R-F Carrier and Modulation Standards**

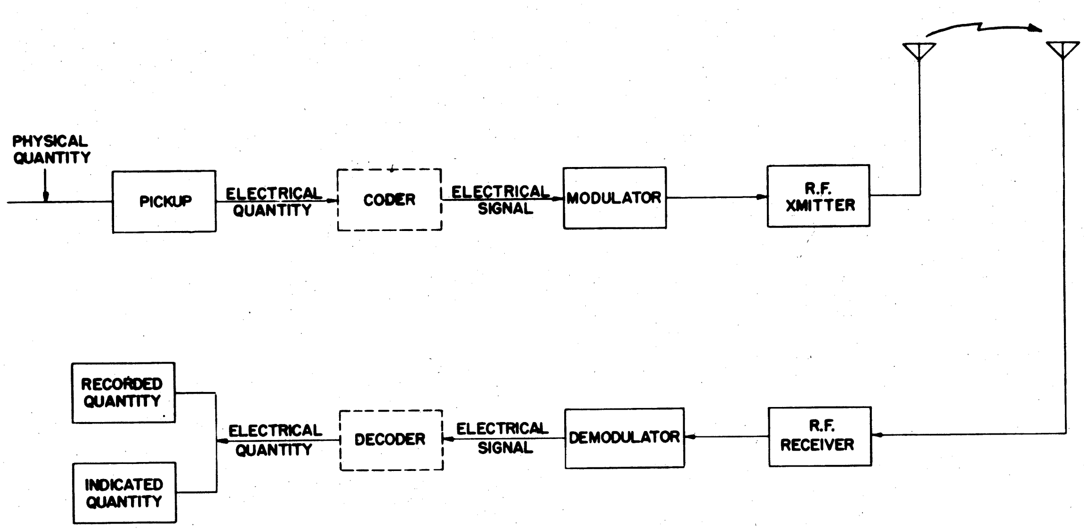
| | System Type | |
|---|---|---|
| | f-m/f-m or f-m/p-m | pdm/f-m |
| R-f carrier freq | 216 to 235 mc | 216 to 235 mc |
| Carrier stability, percent | ± 0.01 | ± 0.01 |
| Type of modulation | frequency or phase | frequency |
| Carrier deviation | ± 125 kc, max | ± 25 to ± 45 kc |
| Power | 100 w, max | 100 w, max |
| Spurious radiation | >60 db below carrier power | >60 db below carrier power |

Illustration #3

## 6. FM/FM TELEMETRY

In the FM/FM system, each transducer voltage output is used to deviate proportionally the frequency of a FM subcarrier oscillator. (Illustration #4.) This next slide shows the basic block diagram for a radio telemetry system. The various subcarriers then are mixed and this composite is used to modulate the FM transmitter.

(Illustration #5.) As can be seen by this chart, there is considerable wastage of RF spectrum. Of the total 80 Kc available, little more than 3% of the total spectrum is available for use in transmitting data. With this amount of spectrum available, it is of primary concern to the flight test instrumentation engineers to make maximum economic use of what is available.




BASIC SCHEME OF RADIO TELEMETRY

Illustration #4

**Subcarrier Bands**

| Band | Center Frequency (cps) | Max Deviation (percent) | Freq Response (cps) |
|---|---|---|---|
| 1 | 400 | ±7.5 | 6 |
| 2 | 560 | " | 8.4 |
| 3 | 730 | " | 11 |
| 4 | 960 | " | 14 |
| 5 | 1,300 | " | 20 |
| 6 | 1,700 | " | 25 |
| 7 | 2,300 | " | 35 |
| 8 | 3,000 | " | 45 |
| 9 | 3,900 | " | 59 |
| 10 | 5,400 | " | 81 |
| 11 | 7,350 | " | 110 |
| 12 | 10,500 | " | 160 |
| 13 | 14,500 | " | 220 |
| 14 | 22,000 | " | 330 |
| 15 | 30,000 | " | 450 |
| 16 | 40,000 | " | 600 |
| 17 | 52,500 | " | 790 |
| 18 | 70,000 | " | 1,050 |
| A | 22,000 | ±15 | 660 |
| B | 30,000 | " | 900 |
| C | 40,000 | " | 1,200 |
| D | 52,500 | " | 1,600 |
| E | 70,000 | " | 2,100 |

Bands A through E are optional and may be used by omitting adjacent bands as follows:

| Band Used | Omit Bands |
|---|---|
| A | 15 and B |
| B | 14, 16, A, and C |
| C | 15, 17, B, and D |
| D | 16, 18, C, and E |
| E | 17 and D |

Illustration #5

Under this system the maximum frequency response of any single channel is 2100 cycles which can be transmitted on the 70 Kc subcarrier channel when using a deviation of plus or minus 15%. When using plus or minus 7 1/2% deviation the maximum frequency response is just a little over 1,000 cycles.

It was determined when the IRIG specifications were originally set up that a modulation index of 5 would be used in order to provide a good signal to noise ratio. As an example of what this means, the 70 Kc channel, the highest frequency channel available, with a deviation of 7 1/2%, provides an actual deviation of approximately 5 Kc. Dividing this 5 Kc by the modulation index of 5 gives us the maximum frequency of the data that can be transmitted over that channel, in this case 1,000 cycles. A thousand cycle channel of data normally is used for handling vibration data. This, in manned aircraft, was about as high as any vibration that existed. Today, in such planes as the B-58, which is a relatively small plane with 4 powerful engines, vibration and accoustical noises must be studied that range up to 15 to 20,000 cycles. With the IRIG standards there is basically no way of transmitting this type of data to the ground.

As the overall business of transmission of data has developed, it has been found that approximately 90% of the required information actually has the frequency response of around 2 to 3 cycles, that is that the maximum frequency of the channel of data is 2 or 3 cycles. The lowest subcarrier is the 400 cycle channel which will handle one channel of data which could range as high as 6 cycles. Obviously, other means had to be developed for handling large quantities of low frequency data. Conversely, in most flight tests about 10% of the data--the vibration and other high frequency data requires 90% of the spectrum available.

As a result of this situation, sampling systems were developed.

## 7. SAMPLING SYSTEMS

The earliest sampling system was that in which the RF carrier was modulated directly by what is commonly called commutated pulse amplitude data (Illustration #6.) A commutator basically is a high speed mechanical wiper which sweeps over a relatively large number of contacts which are connected to transducer outputs. This commutator's wiper moves from point to point producing a pulse amplitude output in serial form modulating the carrier.

IRIG standards were also set up for handling this low frequency data by commutation. A generally used standard for pulse amplitude, which was used to directly modulate a subcarrier oscillator, was a 30 point switch on which the wiper rotated 10 times in a second. This produced a wave train of 300


Illustration #6

samples per second, the pulses all being of constant width and with amplitude varying according to the transducer output voltage level. Normally this 300 samples per second output was used on the 22 Kc subcarrier. (Illustration #7.) Here is seen the IRIG standard for Pulse Amplitude commutation on FM subcarriers.

**Commutation Specifications**

| No. of Samples Per Frame | Frame Rate (Frames per second) | Commutation Rate (Samples per second) | Lowest Recommended Subcarrier Bands cps |
|---|---|---|---|
| 18 | 5 | 90 | 14,500 |
| 18 | 10 | 180 | 22,000 (± 15 percent) or 30,000 (± 7.5 percent) |
| 18 | 25 | 450 | 30,000 (± 15 percent) or 70,000 (± 7.5 percent) |
| 30 | 2.5 | 75 | 10,500 |
| 30 | 5 | 150 | 22,000 (± 7.5 percent) |
| 30 | 10 | 300 | 22,000 (± 15 percent) or 40,000 (± 7.5 percent) |
| 30 | 20 | 600 | 40,000 (± 15 percent) |
| 30 | 30 | 900 | 70,000 (± 15 percent) |

Illustration #7

The accuracy of this pulse amplitude data, because of the general state of the art, has not generally been good up until the last year or so. In order to overcome the difficulties of handling pulse amplitude data with its inherent problems of drift and its susceptibility to noise, a system of pulse width or pulse duration modulation was developed, which has been used as a standard by most aircraft and missile manufacturers for the past 5 to 6 years.

## PULSE WIDTH

In this system of PDM a number of improvements became possible: In the first place, it was possible to increase either the number of channels that the system was capable of handling up to as high as 90; or conversely to increase the number of samples made per second of each channel. In this system the varying amplitude pulses were converted to constant amplitude pulses of varying width. The basic device used for this conversion is called a "keyer" which is so designed that zero amplitudes are converted to widths of approximately 100 microseconds, and the full scale, normally 5 volts amplitudes, are converted to widths of approximately 650 microseconds, with 900 total samples per second set up by the IRIG standards as the basic standard for pulse width.

IRIG standards therefore indicated that for pulse width, 30 channels could be handled, each being sampled 30 times per second, for a total of 900, or 45 channels could be handled, each one being sampled 20 times per second for a total of 900, or 90 channels could be handled, each one being sampled 10 times per second, for a total of 900. (Illustration #8.) Here is illustrated the PDM/FM standards as they are set up by IRIG.

**PDM/FM Standards**

| | | | | |
|---|---|---|---|---|
| No. samples/frame | 30 | 45 | 60 | 90 |
| Frame rate, frames/sec | 30 | 20 | 15 | 10 |
| Commutation rate, samples/sec | 900 | 900 | 900 | 900 |
| Min pulse duration, $T_{min}$ | 90 ± 30 μsecs | | | |
| Max pulse duration, $T_{max}$ | 700 ± 50 μsecs | | | |
| Pulse rise and decay times | 10 to 20 μsecs (constant to ± 3 μsecs) | | | |

Illustration #8

Nine hundred samples per second provides approximately 1100 microseconds for each sample, and as we said before, the width of each sample in pulse width form after conversion was from 100 to 650 microseconds.

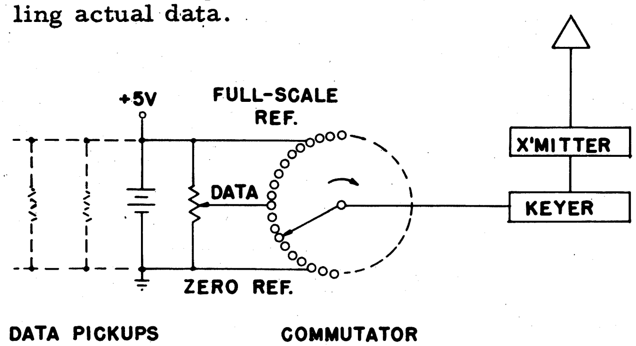
## SAMPLING THEORY

The basic question of how many times you must sample data in a given period of time, such as a second, in order to reproduce the data to a high accuracy on the ground, is one that has been debated since the conception of sampling techniques. Theoretically, it has been determined by the experts such as Dr. Lawrence Rauck of the University of Michigan, that a perfect sine wave should be reproduced to within 1% accuracy when sampling it only about twice. In hardware form, however, it has been found that 5 to 6 samples per cycle of the data must be sampled to assure the instrumentation engineer that he is reproducing the information on the ground to an accuracy of 1% or less of the actual data as it occurred in flight.

If, under maximum standard conditions, therefore, you sample a channel of data 30 times in one second, and assume that you want to sample 5 times per cycle, you therefore know you can handle data with a frequency response of up to 6 cycles.

CHANNEL USAGE

Let us consider what we call a 45x20 system, twenty samples of each channel of 45 channels of data per second. In order that the automatic decommutation equipment located on the ground follow accurately the samples of data without getting them mixed up, confused, and otherwise eliminating the reason for telemetering information, two channels are held in abeyance for synchronization. The real success of pulse width came about by using two additional samples for providing information on the zero and full scale limits, leaving a total of 41 channels for handling actual data.




ELEMENTS OF PW DATA TRANSMITTING SYSTEM

Illustration #9

(Illustration #9.) Normally, the transducers are all powered from a central power supply. By actually transmitting both the ground and the high side of this supply, as shown in this slide, and having an automatic system in the ground station which could look at the zero and full scale input, the drifts that might occur in the system can be automatically compensated for. (Illustration #10.) This slide shows the pulses after they pass through the keyer and how the zero and full scale pulses appear, as well as those for synchronization. The ground station equipment recognizes the zero and full scale values, knows what they should be, compares this information with each of the individual data channels, and corrects for any changes that have taken place. If there is a drift in power supply level, this is even compensated for. As a result the pulse width system was the only one percent accuracy system available for the past few years, and just recently it has been improved to the extent that it is a 0.5% accurate system.

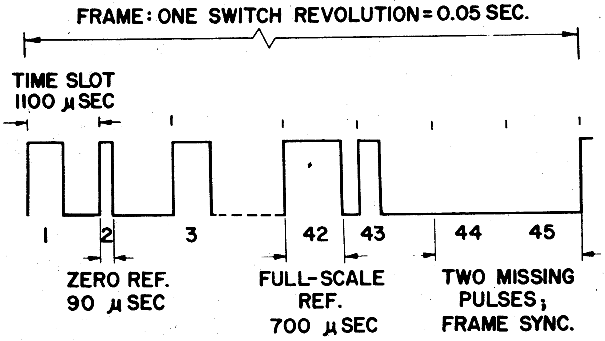



Illustration #10

9. PDM/FM/FM

As systems became more complex it was necessary to transmit both higher frequency data, and large quantities of low frequency data, so a marriage was performed between the FM/FM and PDM/FM system. A 900 sample per second pulse width train is very easily transmitted over the 70 Kc subcarrier, and a few people have been transmitting it quite successfully over the 40 Kc channel. So, in addition to being able to transmit 10 to 15 channels of fairly high frequency data, it is possible to transmit up to 180 or more additional channels of low frequency data over a single RF link. We refer to these systems as PDM/FM/FM systems and the overall signals as a composite signal. (Illustration #11.) How this type of system works out in block diagram form is shown in this slide. The transmitter normally used is a FM crystal-controlled transmitter, of 2 to 5 watts followed by power amplifiers delivering 100 or more watts to the antenna, usually a flush-mounted cavity type. (Illustration #12.) This picture shows a complete PDM/FM/FM package as used in the Corporal missile.

GROUND EQUIPMENT

Up to this time we've talked entirely about the equipment that goes into the missile or aircraft itself. Obviously the equipment in the aircraft by itself does not make up a total system. It is, and must be designed to operate with equipment on the ground.

Basically, on the ground, the data is received through an extremely high gain antenna system, ranging from tri-helix antennas with 10 db or more gain to 60 foot diameter automatic tracking antennas with up to 28 db gain. The receiver is usually crystal-controlled with switchable IF Bandwidths. In almost all cases the received data today is recorded on magnetic tape for later analysis. Simultaneously, however, it may be automatically reduced and played out on strip charts or converted to digital form.

The reduction, demodulation or decommutation process, as it is variously called depending on the specific system being considered, reconverts the original signal to a form that can be monitored or put through further analysis.

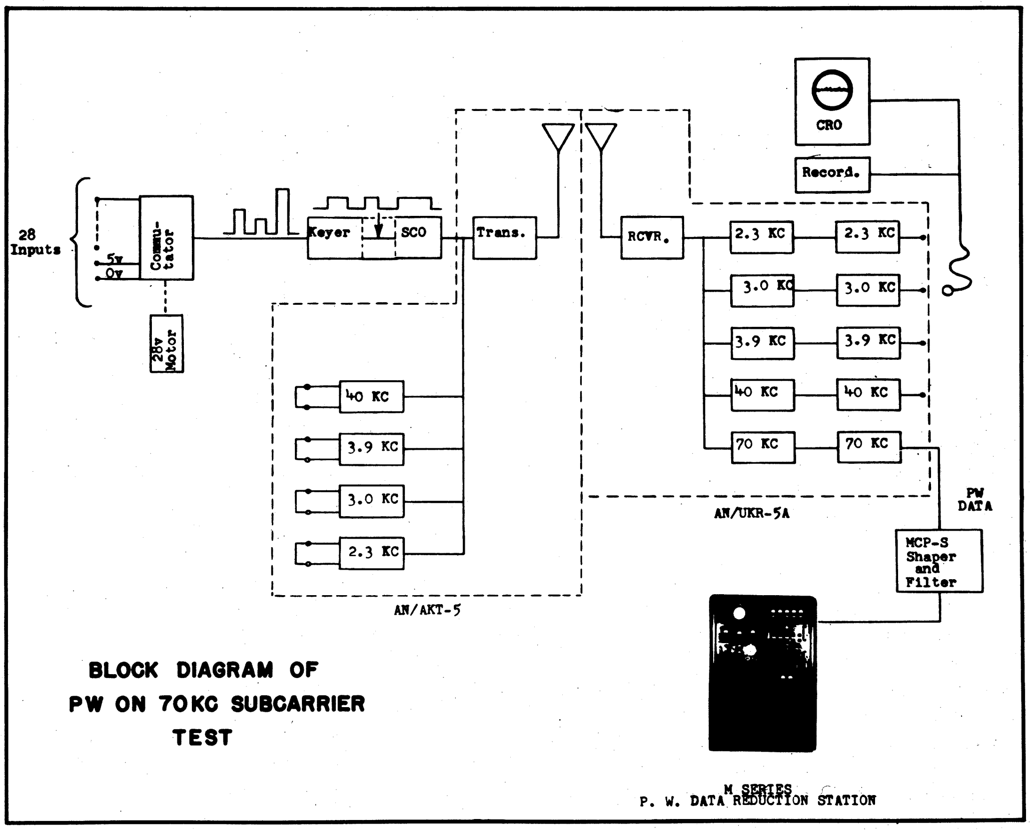



Illustration #11

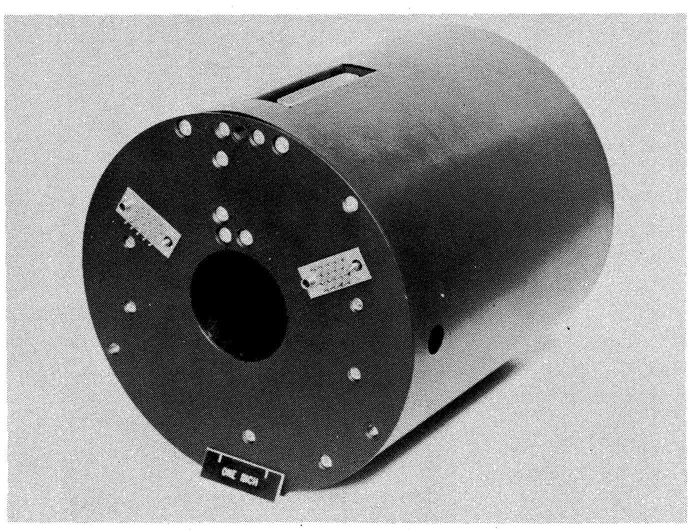


Illustration #12

In FM/FM systems, the composite signal from the receiver is demodulated when put through corresponding discriminators.

If it is a composite PDM/FM/FM or PAM/FM/FM signal the discriminator output representing the commutated or sampled data is put through a further decommutation processing, or possibly directly digitized using the computer to handle the automatic zero and full scale correction.

(Illustration #13.) This view is of a completely new combined PDM and PAM ground station recently introduced by ASCOP. Not only does it handle all IRIG rates, but also all sampling rates from 27 to 3600 sps, and converts to analog form.

(Illustration #14.) Here is seen a typical Pulse Width decommutation system as installed at Edwards Air Force Base.

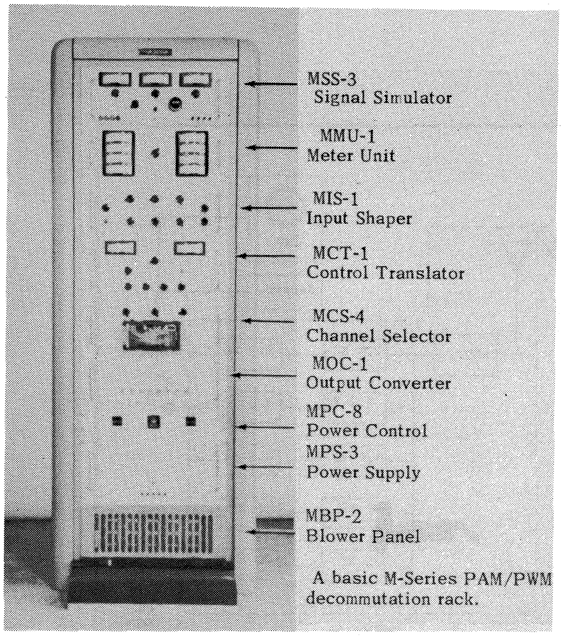



Illustration #13

Decommutation stations for PDM or PAM accept the data, reshape the pulses, correct for any transmission changes using the zero and full scale channels, and put the pulses into a unit generally called a channel selector. This channel selector, working off the synchronizing pulses, distributes the individual pulses into parallel form to gates or storage units. The outputs of these storage units then are fed directly to strip chart recorders, oscillographs, XY plotters, or whatever is required.

The composite pulse width or PAM train may be fed directly after reshaping to a digital converter where they are put into a format compatible with the digital computer which may be available and stored on digital magnetic taps. The higher frequency data from the discriminators can in turn be fed to oscillographs directly, strip charts or digitized for later use in a computer for making mathematical calculations and solving equations.

The tape recorder has come into almost universal usage in the flight test operations. These are highly precisioned pieces of equipment. Once the data is stored it can be played back at any time to completely simulate the flight as it originally took place. (Illustration #15.) This slide shows one of the Ampex Corporation's most recently introduced instrumentation tape recorders. It will handle up to 14 tracks of composite telemetry data.

Nearly every data reduction station today has both analog and digital equipment. Analog equipment is required for quick look and real time editing of the data in order that only those items or those portions of the flight that are valid are put through the computer, which is an extremely expensive piece of equipment

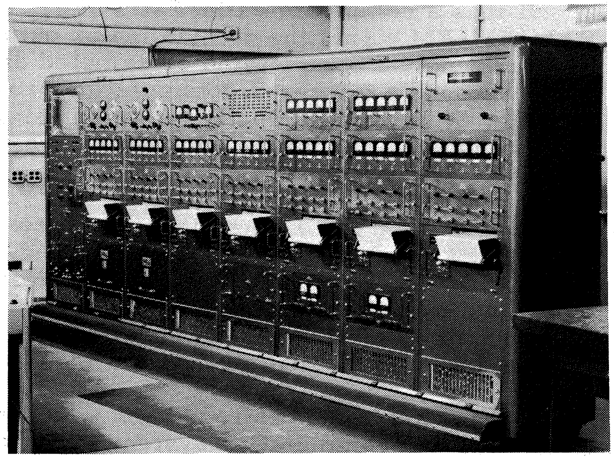


Illustration #14

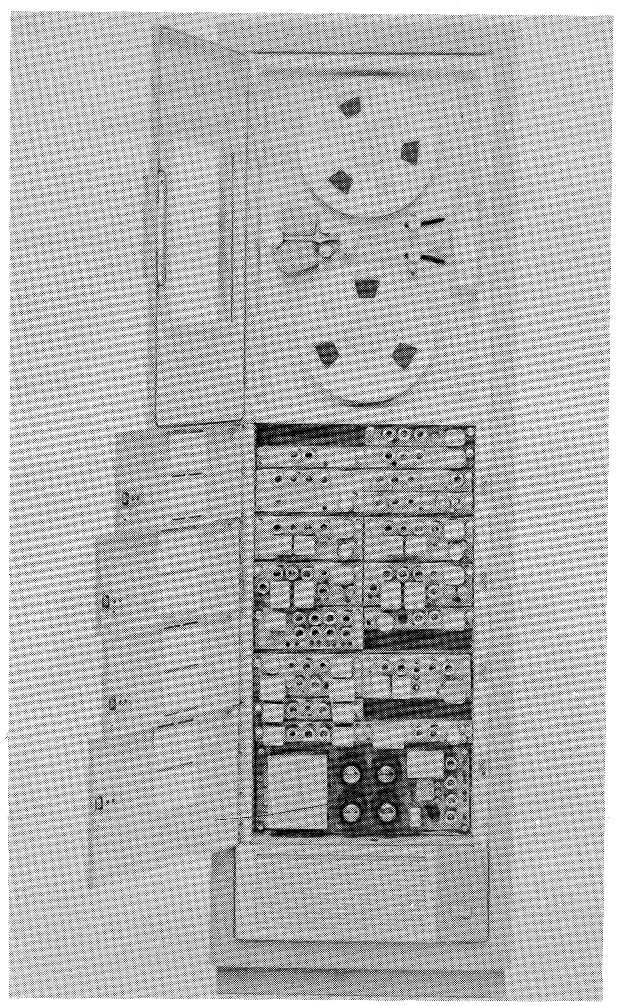


Illustration #15

to use. Some of the data then is digitized to carry out the necessary mathematical calculations and to check the basic parameters of the missile.

So far we have just discussed some of the means and ways that have been developed in order to handle this overall complex problem of obtaining information on the ground as to what's going on up above. Obviously with today's ICBM's, earth satellites, and the forthcoming interplanetary space exploration, the industry is faced with many problems.

## 10. TELEMETRY PROBLEMS

One of our first problems is that of bandwidth conservation. The FCC originally allocated a spectrum range from 216 to 235 Mc. Today this range has been completely outgrown. The number of flights has greatly increased, and with the increasing complexity of the missiles, each one of them is carrying much more equipment, sometimes 5 or 6 transmitters each. The allocated frequency range has now been expanded up to 265 Mc, leaving considerably more room. Also, new frequency ranges in both the 1500 megacycle and 2200 megacycle areas are being allocated. Even then the complete swamping of the spectrum is taking place by the masses of data that the engineers are finding necessary to transmit back on the newer, more sophisticated equipment. And as we mentioned before, there is the problem of handling new high vibration, accoustical type data where there has actually been no frequency made available.

A second requirement has been the ability to improve the accuracy of some of the measurements. Altitudes and total distance away are examples of parameters where it was found important that measurements of approximately 0.1% accuracy is necessary. Simultaneously a great amount of the data does not require an accuracy greater than 5%. (Illustration #16.) Here are the accuracy needs for one typical missile: The overall schedule called for transmission of 100 channels of 3 cycle data each with an accuracy of better than 5%. It called for transmission of 90 channels of 100 cycle data of which most of the channels need not be better than 5%, and few were necessary to be better than 2%, a few better than 1%, and 6 of the 90 required an accuracy of less than 0.1% or better. It was also necessary to transmit 8 channels of 8 Kc data and one channel of 10,000 cycles per second data. These channels also could be transmitted within 5% accuracy.

| | Number of Channels | Frequency Response per Channel | Accuracy Needed |
|---|---|---|---|
| 1. | 100 | 5 cycle | 5% |
| 2. | 90 | 100 cycle | "Most" at 5%<br>"a few" at 2%<br>"a few" at 1%<br>6 at 0.1% |
| 3. | 10 | 3 Kc | 5% |
| 4. | 1 | 20 Kc | 5% |

TYPICAL MISSILE REQUIREMENTS

Illustration #16

Reliability and life of the equipment has always been an important aspect. In almost every case the only reason for firing any missile has been to provide data. If it should happen, and it has from time to time, that telemetry equipment failed to work, the whole point of the firing is lost, along with the hundreds of thousands if not millions of dollars, invested in building the missile. The life of the equipment must be long enough to carry it through all the preflight checkouts and then the actual missile test. Individually, this does not sound like a difficult order. Statistically, however, the equipment must be designed to have a life many times longer than it actually will even be run to make sure every package of telemetering equipment will last as long as necessary, and that every single component operate properly.

Environmental conditions are an area where considerable new thought has had to be placed. With increasing high G levels, higher temperatures, extreme vibration, the actual telemetry equipment itself has had to be as rugged as the missile.

Size and weight has continued to be a battle as the manufacturer is forced to put more and more sophisticated gear in less and less space. In our long range missiles every pound added decreases its firing range as much as 5 miles. As a result, miniaturization and transistorization has been a continuous goal.

The overall telemetry package must also be designed to take a very minimum of power and here again transistorization has come into play.

As we pointed out before from a little different approach one of the major present day problems has been that of handling higher frequency data.

The requirements of the newer missiles and aircraft are such that there has been no facility available for the transmission of high vibration and accoustical type of information.

Certainly, as a result of all these efforts in conserving bandwidth, improving accuracy, improving reliability and life, upping the environmental capabilities, decreasing the size and weight, decreasing the power consumption, we are led to one general conclusion. This is that within the past year telemetry equipment prices have generally increased considerably. In my own company our most recently introduced line of equipment is selling for approximately twice the cost of equipment of a similar type a year ago. But is designed with all silicone transistors, in miniaturized, modular form for long life, high G capability, great vibration and for temperatures to 100°C and up, and it costs more money to build it that way.

## 11. SOLVING THE PROBLEMS

For the past few minutes we discussed the major problems which we are facing in the telemetry industry. Now I would like to point out some of the newer methods that are being adopted to overcome these problems.

## 12. STATISTICAL EQUIPMENT

At our company we took up the problem of bandwidth conservation approximately a year and a half ago as one of the major problems that needed a solution. We have approached this old subject in a completely unique manner, one which has never really been given serious consideration before.

Taking our lead from the knowledge resulting from information theory and statistical analysis we are now just beginning the marketing of equipment which makes it possible to analyse the high frequency data outputs in the air, and to transmit their result to the ground as low frequency data. The information that is being transmitted to the ground is the information which is normally sought out from this high frequency vibration after it is on the ground. However, by handling a 10,000 cycle frequency vibration, for example, in this manner, the output can be transmitted as a channel of 3 or 4 cycle data. This not only relieves the instrumentation engineers of the tremendous job of analyzing the vast amounts of data on the ground, but gives them immediate answers to the questions they are seeking. It was, for example, determined that from vibration data only two factors are really important. This is the proper spectrum of the data, which is actually a measurement of the amount of power at each frequency interval, and the probability of the existence of any frequency vibration in a given random signal. (Illustration #17.) Here is a slide showing a prototype model of ASCOP's spectrum analyses and amplitude probability analyzer which is presently being evaluated by the Army Balistic Missile Agency in Huntsville, Alabama.

Another item in the statistical analysis equipment is that of a time of occurrence device. It was found that in many of these missiles where perhaps five or six transmitters were necessary to handle the data, that some subcarrier oscillators were being used only a very small percentage of the time. For example, it was found that a subcarrier might exist solely to transmit a single transient. Actually, it wasn't the amplitude of the transient that was important, but merely the time that it occurred. By various small transistorized devices these times can now be accurately calculated and transmitted to the ground as very low frequency data, usually on a single pin of a PAM or PDM commutator. (Illustration #18.) The next slide is of a prototype of such a Time of Occurrence Device.

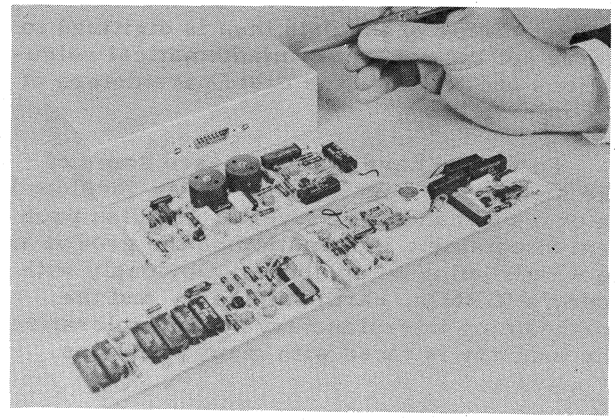


Illustration #17

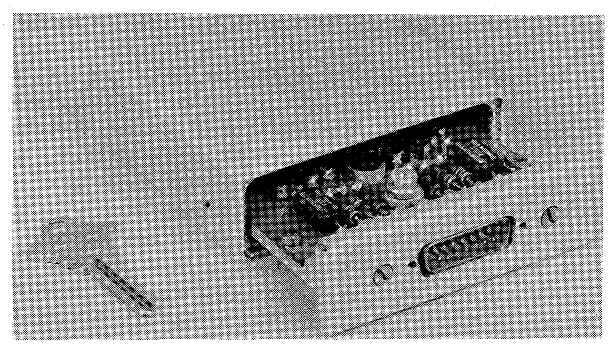


Illustration #18

## 13. HIGHER ACCURACIES

In order to receive higher accuracies for those few channels where it is necessary, a number of companies are introducing pulse code modulation equipment making use of digital techniques. These systems are based upon sampling at extremely high rates, perhaps 25 to 50,000 samples per second. Each sample is converted to a digital code and transmitted to the ground at extremely high bit rates ranging up to 500,000 bits per second.

As an example, such a system might be

a 100 channel system sampled at 24,000 samples per second or 240 samples per channel per second. Divided out in this way it can be seen that each of these 100 channels can handle data up to approximately 50 cycles, rather than 3 to 5 cycles as in some of the other systems. By putting the data through more than one channel this frequency response can be doubled or tripled. There are numerous advantages to such a system. One of the primary ones claimed by the various manufacturers is that once data is put into a digital code, it retains its accuracy. The basic fact here is that there actually are only a very few channels where such accuracy is required and usually not too many channels carrying 50-200 cps information. Furthermore, the major problem in obtaining a high accuracy is in the transducer itself. Mathematically there is not much gain in taking the output from a transducer, which itself is only 5% accurate, and transmitting it on a 0.1% accuracy system. These new systems generally provide quite easy access to a digital computer. It is necessary, however, for analog display, to go through a conversion system on the ground. Furthermore, they eat up spectrum space at a tremendous rate and generate masses of data which are never needed. They are, however, today in their glamour stage and are undoubtedly going to be used to a considerable extent on some of the newer missiles.

## 14. MINIATURIZATION

As we mentioned before the packages are becoming much more dense and much more miniature in order to fit the small crevises and corners that remain in a missile for telemetering purposes. (Illustration #19.) Here

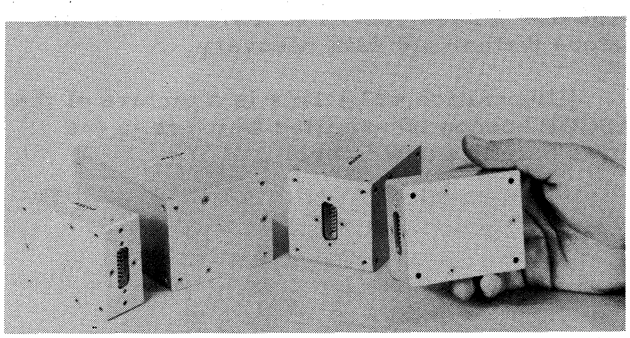


Illustration #19

are shown a completely new modular concept. From these individual, interchangeable units complete packages of various sizes and combination can be made up. (Illustration #20.) This slide shows how such a package can be put together.

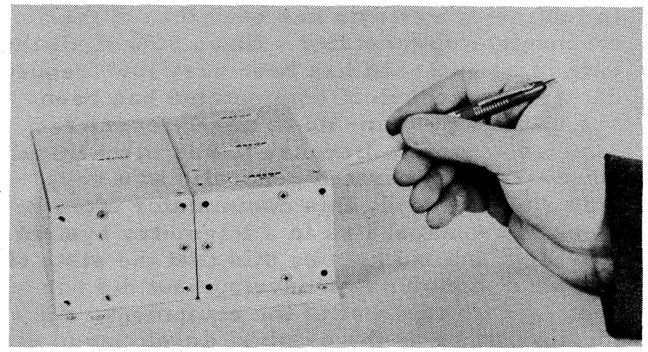


Illustration #20

## 15. HIGHER R.F. FREQUENCIES

One of the brightest new fields for the telemetry industry will be in the 1500 megacycle and the 2200 megacycle ranges. It is going to be a tremendously costly proposition to the Government to convert to the new frequencies as needed over the next 5 to 10 years, but fortunately, although it appeared for awhile that the telemetry industry would lose the 200 megacycle range altogether, this does not seem to be the situation at present and the millions of dollars worth of equipment at the flight test ranges and the aircraft and missile manufacturers can be used for many years to come.

## 16. MODERN PAM SYSTEMS

Among some of the newer systems on the market are pulse amplitude type systems which sample at very high rates, some of them up to 40,000 samples per second. I mentioned earlier that pulse width became the adopted standard because of drift and other problems in pulse amplitude systems. Within the past year or so pulse amplitude has finally come into its own and there are highly reliable and accurate pulse amplitude systems on the market now.

In order to save and conserve even more spectrum space, one pulse amplitude system is now out which is known as a non-return to zero system. In this one, even the spaces which would normally exist between two pulses are used for additional information transmission.

## 17. MODERN PDM SYSTEMS

Pulse width systems are now available up to 3600 samples per second, and there is some talk of systems under study that will handle up to 28,000 samples per second.

## 18. COMMUTATORS

Probably one of the greatest weaknesses in telemetry systems has been that of the mechanical commutator. Since 90% of all the data to be gathered has been very low frequency data, the mechanical commutator has been one of the key elements in nearly every telemetry system. Because it was mechanical, however, and operated generally at a very high rate of speed, this commutator often became the weakest link in a telemetry system. I do not want to imply by this that the state of the art of commutator development did not keep up with the rest of the equipment, since my company was the original developer of the mechanical commutator. I would be the last to admit this. Tremendous strides have been made in the development of this equipment, but because of the very fact it was a mechanical gadget it remains one of the weaker areas in the system.

Within the past year there has been introduced on the market a line of all transistorized solid state commutators which have proven themselves to be fully reliable. These items, although costly, will undoubtedly become widely used in our missile programs. (Illustration #21.) Here is a view of a typical all electronic Pulse Width Multicoder. This is

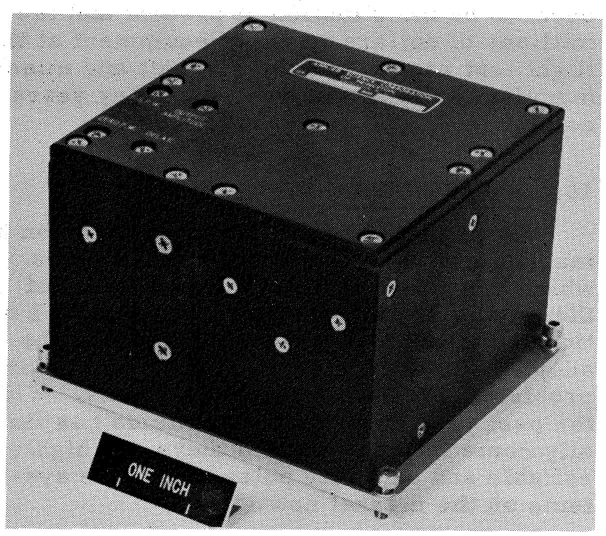



Illustration #21

all silicon transistorized, including the commutator. It operates continuously up to 100°C and withstands very high vibration and shock.

## OTHER PROGRAMS

There is some talk within the industry of going to other techniques such as pulse position and pulse time systems. So far no company has actually used either of these in a modern form.

## 19. NEW FM/FM TECHNIQUES

As we pointed out before, the IRIG specifications have been something of a strait jacket, particularly to the adoption of any new FM/FM techniques. One of the methods that seems to have promise is the breaking down of each RF carrier into narrower, equal frequency divisions, perhaps each 100 cycles wide. These then can be used individually to handle relatively low frequency data, or two or more can be replaced by a wider band filter for handling higher frequency data.

## 20. FLEXIBLE PDM/FM/FM

As we discussed before, the standard for pulse width on FM/FM has been primarily for use on the 70 Kc channel. A major breakthrough also has been on this area, and it is now possible to provide pulse width on any of these standard IRIG, subcarrier oscillator frequencies.

As the subcarrier frequency decreases, the number of samples per second that can be transmitted through it also decreases proportionately, of course.

## 21. TRANSMITTING EQUIPMENT

By reducing the power and weight of the airborne transmitting equipment and adding greater complexity to the ground-based receiver equipment through the adoption of phase-lock techniques, considerable progress has been made. This not only reduces the weight of the equipment to be carried but also increases the distance over which effective transmission can be successfully carried on. A phase-locked receiver developed by the Jet Propulsion Lab made it possible to receive signals from the Army's Explorer at levels of -150 db. Phase-locked subcarrier discriminators further aid data recovery.

(Illustration #22.) This is a picture of the ASCOP beacon transmitter which is in the Atlas Satellite now in orbit.

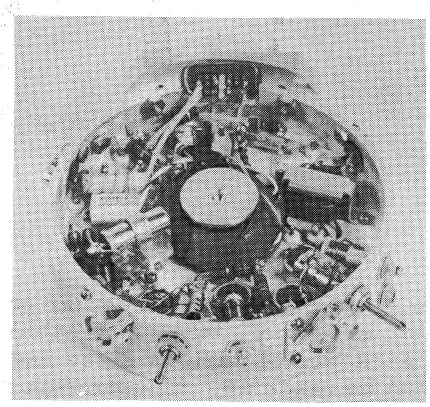


Illustration #22

## 22. SYSTEMS CONCEPT

As has been developing in the whole armament industry, the systems concept has caught up fully with the telemetering business. As a result, each company in this industry not only sells its own equipment, but has the opportunity and finds the necessity, to sell complete integrated telemetry systems, where they include other companies' equipment, often competitors, in with their own.

These systems may be either airborne systems or ground based systems.

As an example of this type of system, ASCOP, within the last 30 days has signed a contract with the ITT Laboratories, for the ground based equipment required for telemetry over the entire Eglin Gulf Missile Test Range, which is now being just developed. In this system we not only include our own pulse

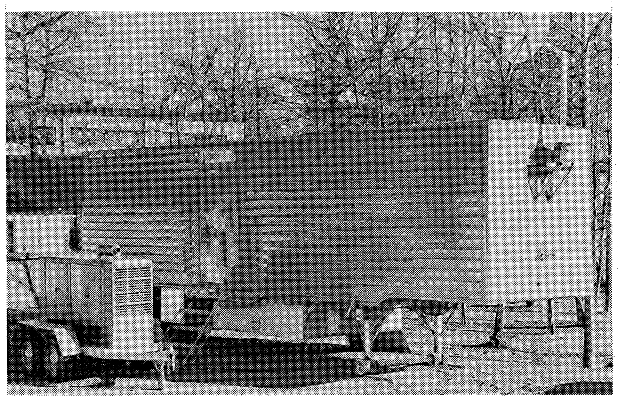


Illustration #23

width decommutators but also include FM discriminators, radio receivers, test equipment and the other items that go to make up an entire system, purchased from other companies. The industry has developed to such a point that unless you sell the complete system, in many cases you will not sell your own equipment at all. (Illustration #23.) Here is illustrated an external view of a complete ground based telemetry system we shipped the first of this month to Patuxent Naval Base, Maryland. (Illustration #24.) This cutaway view of the Patuxent Van Model shows the installation of the FM/FM equipment, the PDM equipment, tape recorder and strip chart recorders. Because this unit is on wheels it can be particularly flexible in its placement and movements. (Illustration #25.) Inside the finished van we can see here the actual equipment and its placement.

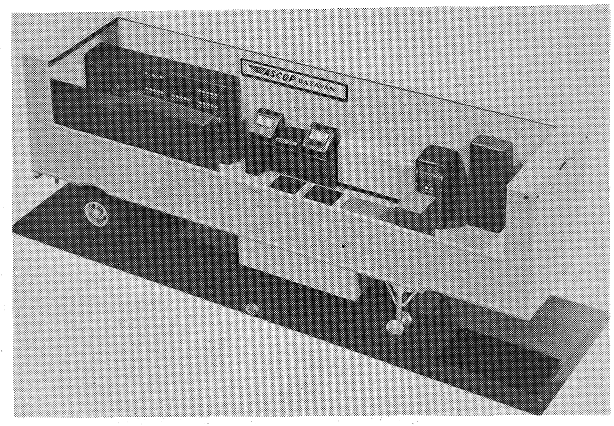


Illustration #24

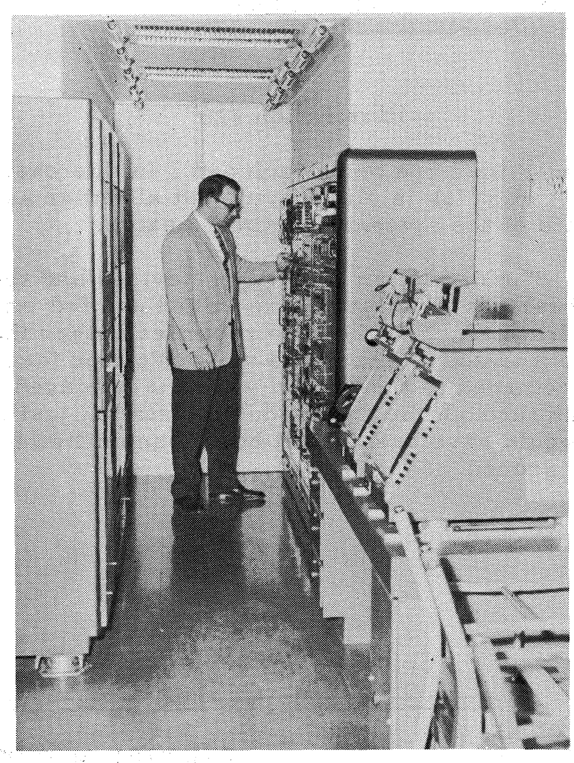


Illustration #25

## 23. SPECIAL FORMS OF TELEMETRY

So far we have discussed telemetry in general, how it was developed, some of the present day problems and some of the newer techniques used to solve these problems. There are also special forms of telemetry which, while they do not exactly fall within the definition of transmitting data from one point to another, the industry as a whole, generally categorizes them as such. (Illustration #26.) Shown on this slide is a typical airborne tape recorder, the Ampex 800 which will record up to 14 tracks of information. This is equivalent to up to 1400 channels of telemetering data. The magnetic tape recorder is actually located in the aircraft or missile. This, of course, is not generally possible in large missiles, but in small missiles which can be parachuted to the ground after

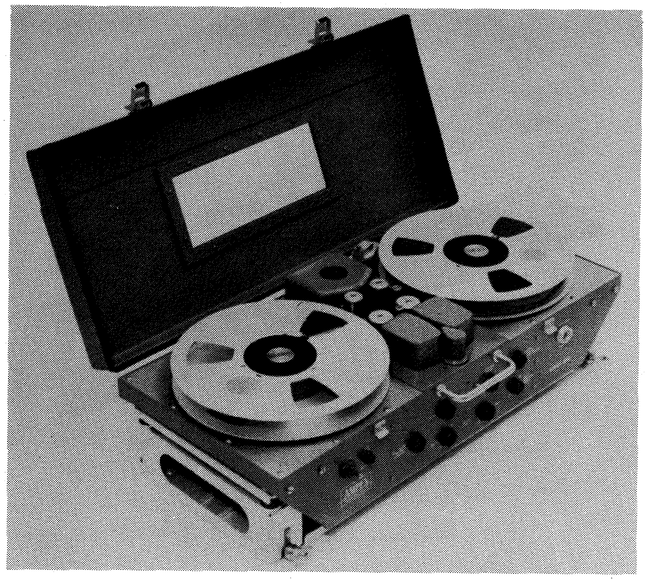


Illustration #26

firing, they are being included. In this case the radio link is eliminated, but all other aspects of the system remain the same.

The data from the coding devices and the subcarrier oscillators are mixed and fed into a single track of the tape recorder rather than into a transmitter. This magnetic tape then is returned to the ground where it is played back through the data reduction station just as it would have been had it been transmitted to the ground.

## 24. CONCLUSION

In the typical data reduction station in today's missile instrumentation center there is so much equipment involved and its complexity is so great that at times there seems to be a tendency to forget the real purpose for its existence. Basically, the only reason that it exists is to provide as automatically, and quickly as possible, answers to the designers of the missile. This is the only reason for its existence. Under ideal conditions, after a missile is fired, the data will be successfully gathered, transmitted to the ground, reduced through the data reduction equipment, and answers fed immediately back to the designers, so that any changes necessary, can be made before the next firing of the missile. Unfortunately, even today the amounts of data that are gathered are so massive, and the reduction process is so tedious, that the design engineers often do not get their needed data until it is too late to use.

As a result it is our aim in the telemetry industry to furnish airborne coding equipment, transmitting equipment, and data reduction equipment that is so automatic and so straightforward that as the missile rises from its pad, the final answers that the design engineer is looking for will start flowing from the equipment on the ground. When this can be achieved, the number of flights necessary to fully develop a missile can be greatly reduced, and the burden that all of us as tax payers must pay for these programs can be greatly lessened.

# AN ACCOUNT OF THE DISCOVERY OF JUPITER AS A RADIO SOURCE

**by K. L. FRANKLIN, Associate Astronomer**
**American Museum—Hayden Planetarium**

Vannevar Bush has said that there is no more thrilling experience for a man than to be able to state that he has learned something no other person in the world has ever known before him. This experience is not rare in the life of a successful research scientist, as witness the papers published in our journals and to be presented to this meeting in the next few days. Often, such an experience comes gradually and almost without one's awareness; but occasionally a discovery is made with dramatic swiftness which leaves the participants in a state of excitement. I have been lucky enough to be included in such an event, and I have been asked to recount this anecdote as an introduction to this symposium.

When I arrived at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington as a Research Fellow, on September 1, 1954, I was introduced to the world's largest (and least conspicuous, as Bernard Burke remarked) radio telescope. This Mills Cross, described in the literature, had been constructed during June and was being operated by Burke. Dr. M.A. Tuve, Director of D.T.M., suggested that I work with Dr. Burke on the 22.2 Mc/s Sky Survey for which the Mills Cross was built. I had to learn many things that I still find mysterious, and it was interesting to participate in the development of some of the tools of radio astronomy.

The receiver and auxiliary equipment were constantly being improved during the first few months of 1955. In order to discern the results of each improvement, we left the pencil beam (about 2.5$^{\circ}$ wide to half-power points) directed to the declination of the Crab Nebula, the strong radio source in Taurus, and compared records obtained before and after each modification. We decided to scan the region near the Crab Nebula in order to build up a two-dimensional picture of this part of the sky. Arbitrarily, we directed the beam southward by about 1$^{\circ}$ at three- or four-week intervals.

The records themselves showed the characteristic hump as the Crab Nebula passed through the pencil beam. This was followed by a smaller hump, lasting the same 15$^{m}$, attributed to IC443. At times the records exhibited a feature characteristic of interference, occurring some time later than the passage of the two known sources. This intermittent feature was curious, and I recall saying once that we would have to investigate the origin of that interference some day. We joked that it was probably due to the faulty ignition of some farm hand returning from a date.

We decided to present the material we had to the Princeton meetings of the A.A.S. in April, 1955. Accordingly, Burke assembled all the records of the Taurus region for the first three months of 1955 in preparation for the reductions. He temporarily laid aside those with interference on them, and concentrated on the two-thirds remaining. Burke noticed a gentle rise and fall that was usually present some time after IC443 had crossed the meridian. To investigate this feature more fully, he examined the records containing interference, finding that the interference usually occurred at the time the rise-and-fall was supposed to be present. He was then startled to find that the interference always occurred at almost the same sidereal time. A strange rural romance this was turning out to be! As spring drew nearer, our swain was returning home earlier and earlier, each evening.

Since the source of the "interference" was clearly attached to the sky, we immediately went to an atlas to find anything that might be obvious. A peculiar galactic cluster, and an interesting planetary nebula were candidates, but they were ruled out when we noticed that this strange source was not always at the same right ascension. It appeared to drift westward, slightly, over the three-month interval, so that in March, the two interesting objects were not in the beam at the time of the recorded event.

The late Howard Tatel, a man of many parts, was present in the laboratory, working on some of his seismic records. He and Dr. Tuve were the principal investigators at DTM of the distribution of hydrogen in the galaxy. At the suggestion of Dr. Richard Roberts of DTM, Tatel had looked at Jupiter a few nights before with the H-line equipment, and found nothing. Having this in mind, he somewhat facetiously suggested to Burke and me that our source might be Jupiter. We were amused at the preposterous nature of this remark, and for an argument against it I looked up Jupiter's position in the American Ephemeris and Nautical Almanac. I was surprised to find that Jupiter was just about in the right place, and so was Uranus. Here was something which needed clearing up. Unfortunately, we had no more time that afternoon to work on it, because we had to go out to the Mills Cross and work until evening. As twilight came and went, we were delighted by a fine, clear sky. Burke asked me what one exceptionally bright object was, almost on the meridian. We had a good laugh when I told him it was Jupiter.

The next morning, I plotted the right ascensions as a function of the date for the points of beginning and ending of each recorded event, and drew a smooth curve through the points locating each phenomenon. I then placed the right ascensions of the two interesting galactic objects on the plot, and followed this with the positions of Uranus throughout the observing interval. The objects of fixed right ascension were represented by horizontal straight lines, and Uranus exhibited the slow westward change due to its retrograde motion at the time. The galactic objects nearly fit within the region of the plot bounded by the two similar curves representing the limits of the recorded events, but these objects could not represent the change of right ascension with date. Uranus, while apparently within the beam early in January, did not drift westward nearly as rapidly as the events required. At this point in the growth of the diagram, I began to plot the right ascensions of Jupiter. As I plotted each point, Burke, who was watching over my left shoulder, would utter a gasp of amazement. Each point appeared right between the boundary lines representing the beginning and end of each event! The meaning was exquisitely clear: these events were recorded only when the planet Jupiter was in the confines of the narrow principal beam of the Mills Cross. Not only did this source have the same direction in space as Jupiter, but it also exhibited the same change of direction as Jupiter did during its retrograde loop of 1955. No other object could satisfy the data: the source of the intermittent radiation was definately associated with Jupiter!

Such is the actual story of this very unexpected discovery. The events which followed are esentially anit-climactic, but it may prove amusing to recount one other personal part in the story of Radio Jupiter. After the announcement of the discovery was made at Princeton, the National Broadcasting Company requested that we make a tape recording of this noise which they could put on their first Monitor program. They supplied the recorder and we hooked it into the equipment. Only fifteen minutes each day were possible in which we could receive any radiation from Jupiter. On Easter Sunday, there was a fine event recorded on the paper tape, but the magnetic recorder was not operating until the next day. Each afternoon, I raced the twenty miles out to the field in order to be on hand when and if Jupiter should be active. Roughly three weeks later the next event occurred on a Friday afternoon. Until I played the tape for everyone at DTM on Monday morning, I was the only one in the world who had heard Jupiter and who knew it.

Naturally, we wrote to our colleagues in other parts of the world. C.A. Shain, in Australia, immediately began observations which confirmed our identification, and he searched his old records for possible pre-discovery observations. It turned out that he had actually received noise from Jupiter in 1950, but had attributed it to interference. Those pre-discovery records have proved of great value as early-epoch data, and have been discussed in the literature.

Our identification of Jupiter as a radio source is not based directly on reasoning, but more on luck. (Professor Herbert Dingle once described this as the real scientific method, in a talk before the National Science Foundation.) We were led into it by the nature of our equipment; a very narrow pencil beam. Shain had a broad beam which was suited to his needs, but which enabled him to overlook the celestial source of "interference" appearing on his records. Another curious bit of chance shows up when we reviewed our arbitrary sothward redirection of the pencil beam: we were inadvertently following Jupiter southward as well as if we had planned it! (Incidentally, we never did learn the cause of the rise and fall which started all this.)

A further favorable attribute of much of the radiation from Jupiter is its intensity. It can be very powerful, even more intense than Cassiopeia A, the strongest source in the sky, at this frequency, around 20 Mc/s. Only the active sun is apparently stronger, at times. Thus, when Jupiter is acting well, it is not difficult to observe, as radio sources go. It is well, however, to recall that any radio source is very weak compared to the general amount of noise entering the antenna system, and even sometimes produced in the equipment, itself. As a reminder to the prospective observer of extraterrestrial radio noise, I shall conclude by offering the following motto for radio astronomers (with apologies to Gertrude Stein): Signals in the grass, alas!

COMMUNICATION RECEIVED

The Board of Directors of the Radio Club of America feel that the letter reprinted below is worth the reading time of all members.

*The McBride Company, Inc.*
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Brideco, N. Y.

December 8, 1958

MEMO: Re RADIO CLUB OF AMERICA'S 50th ANNIVERSARY

1. President Walter Knoop's Nov. 19, 1958 letter to Club members stated:

> "The greatest problem facing this Club today is the influx of "young blood". As a young man in his twenties, your President remembers with great admiration and respect the opportunity of eating in the same dining room with Armstrong, Adm. Hooper, Beverage, Hazeltine, Heising and others...."

This remark emphasizes the intensely personal attribute of the Radio Club of America, and the strong appeal that this has for those affiliated with it. The Radio Club's unique personality is directly due to this appeal -- it is the individual's club, the researcher's, the pioneer's, the inventor's "home". It is the place -- in a conformist-ridden industry dominated by a "big business" complex -- for the independent thinker, businessman, and professional, be he small business owner or manager, or independent inventor.

The conserving of the pioneer spirit in independent investigation and achievement (especially in this tense era), and of the stressing of the value of the individual personality as against the mass-thinking is not only of pre-eminent importance to us as a nation, but more especially so in the field of science and engineering. The Radio Club of America is the indicated place and forum for the small, dedicated number of independent persons whose continued existence under a free exercise of intellectual effort is a pre-requisite for the progress of the electronic arts.

2. With its strongly individualistic appeal, the Radio Club of America can therefore continue to grow and prosper, if it will:

a. Offer a youthful, invigorating atmosphere for the free expression of independent effort and thinking.
b. Continue its policy committed to the value of the individual and his worth.
c. Give greater recognition to individual achievement in fields of unorthodox investigations, especially among the younger members, as well as non-members.
d. Help to point out to youth the expanded opportunities for individual achievement in all fields of electronics.
f. Provide the younger members with sound guidance and assistance through the accumulated experience of its senior membership.

The above can serve as the Radio Club's POLICY and cornerstone to justify the beginning of its second half-century of existence.

3. In accentuating this typical American pioneer spirit which seems to be subject to considerable attack by the pressure of various ideologies and groups today, the Radio Club would be performing a most useful duty of paramount importance to every individual American, as well as for the security of the country.

(Original Signed by)
Lloyd Jacquet

# RADIO CLUB

**1909–1959**

## *50th Anniversary Banquet*

## FRIDAY, DECEMBER 4, 1959

## Plaza Hotel, New York City

**Cocktails 6:30 P.M.** **Ladies Invited**

**Dress Informal**

**Reserve This Date ! !**

*– Further Notices Will Follow –*

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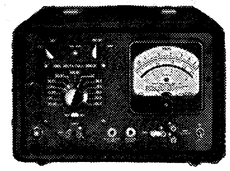
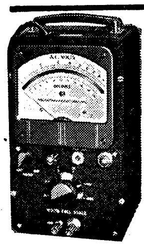
## TRUE RMS INDICATION — MODEL 320



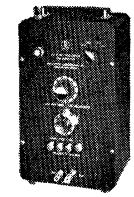
Voltage Range ........................ 100 μv — 320 v
Frequency Range ................. 5 cps — 500 kc
Accuracy ..................... 3% 15 cps — 150 kc
5% elsewhere
Stability of Internal Calibrator ............ 0.5%
Input Impedance . . .
10 megs shunted by 18 μμf below 10 mv
10 megs shunted by 8 μμf above 10 mv

## AUDIO to 250 kc — MODEL 300D



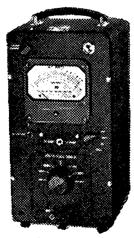
Voltage Range ................................ 1 mv — 1000 v
Frequency Range ........................ 10 cps — 250 kc
Accuracy ................................ 2% ENTIRE RANGE
Input Impedance .......... 2 meg shunted by 15 uuf

## DC & AC PRECISION CALIBRATOR — MODEL 420



Voltage Range .......... 0-10 v RMS; Pk-to-Pk; or DC
Frequency (Std. Model) .............................. 1 kc
(other values on special order)
Accuracy (long term) Better than 0.5% above 1 mv
Distortion and Hum ..................... Less than 0.25%
Setting Resolution Approaches 0.01% above 10 mv
Output Impedance (AC) .... 2-20 ohms depending on range setting

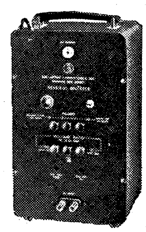
## SUB-AUDIO to 150 kc MODEL 302C



Battery Operated

Voltage Range ............................ 100 μv — 1000 v
Frequency Range ............................ 2 cps — 150 kc
Accuracy ................................ 3% 5 cps — 100 Kc
5% elsewhere
Input Impedance ........ 2 meg shunted by 10 μμf*
*Shunt capacitance, 25 μμf on two most sensitive ranges

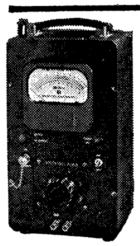
## SENSITIVE INVERTER — MODEL 700



For Measuring DC Voltages when combined with any AC Voltmeter

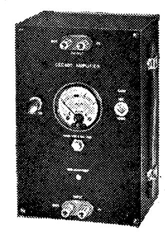
Voltage Range ............................ 1 μv — 100 v DC
Ratios DC Input to RMS Output ........ 1:100 & 10:1
Accuracy ................................ 1% 100 μv — 100 v
Input Resistance .................... >10 meg for 1:100
50 meg for 10:1

## PEAK-to-PEAK — MODEL 305



Voltage Range ................ 1 mv — 1000 v pk-to-pk
Frequency Range ...... 10 cps — 100 kc (sine wave)
Pulse Width ............................ 3 μsec — 250 μsec
Min Rep Rate ........................... 20 pulses per sec
Accuracy .......................................... 5% for pulses
Input Impedance ............ 2 meg shunted by 8 μμf*
*Shunt capacitance, 15 μμf on two most sensitive ranges

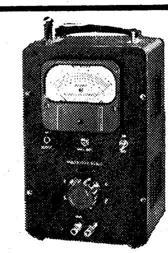
## DECADE AMPLIFIER — MODEL 220B



For Increasing the Sensitivity of any AC Voltmeter by 10 or 100 times

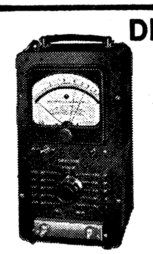
Voltage Range ................................ 20 μv — 50 mv
Frequency Range .......................... 10 cps — 150 kc
Accuracy ................................ 2% ENTIRE RANGE
Input Impedance ............ 5 meg shunted by 15 μμf

## AUDIO to 2 mc — MODEL 310A



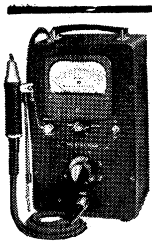
Voltage Range .............................. 100 μv — 100 v
Down to 40 μv at reduced accuracy
Frequency Range ............................ 10 cps — 2 mc
As null detector 5 cps. — 4 mc
Accuracy .................................. 3% 15 cps — 1 mc
5% elsewhere
Input Impedance ............ 2 meg shunted by 9 μμf*
*Shunt capacitance, 19 μμf on two most sensitive ranges

## DIRECT READING CAPACITANCE METER — MODEL 520



Capacitance Range .................. 0.01 μμf to 12 μf
in 9 decade ranges covering over a billion to 1
Accuracy ..................................... 2% above 0.1 μμf
5% below 0.1 μμf
Capacitor Power Factor ..................................... 0.15
Test Frequency .................................................. 1 kc

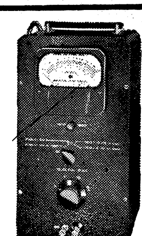
## AUDIO to 6 mc — MODEL 314



Voltage Range ................................ 1 mv — 1000 v
(100 μv — 1 mv without probe)
Frequency Range ............................ 15 cps — 6 mc
Accuracy ................................ 3% 15 cps — 3 mc
5% elsewhere
Input Impedance ............ 11 meg shunted by 8 μμf
(1 meg shunted by 25 μμf without probe)

**ACCESSORIES** are available for all voltmeters to extend voltage measurements down to 20 μv and up to 10 kv, and to measure currents from 0.1 μamp to 10 amp, and to provide DC from the Model 300 Voltmeter to drive external recorders or remotely located meters.

## INFRASONIC to 30 kc — MODEL 316



Voltage Range ................ 20 mv — 200 v pk-to-pk
Frequency Range ........................ 0.05 cps — 30 kc
(Down to 0.01 cps with correction)
Accuracy ................................ 3% ENTIRE RANGE
Input Impedance .......... 10 meg shunted by 17 uuf or 40 uuf depending on setting

**BALLANTINE LABORATORIES, Inc.**