International Telemetering Conference

London 1963

VOLUME ONE

of the Conference Proceedings

(Papers Presented at Conference Sessions)

ITC London 1963

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Institution of Electrical Engineers . Savoy Place . London . W.C.2

International Telemetering Conference London 1963

VOLUME I

(PAPERS PRESENTED AT CONFERENCE SESSIONS)

ADDENDA AND CORRIGENDUM

Page 56 — "Remote Phase Comparator" by H. J. Ward and H. B. Chatterji.

The authors are at Standard Telephones and Cables Ltd., Integrated Electronic Systems Division.

Page 162 — "The Telemetry of Low-Level D.C. Signals" by R. C. Foss.

Mr. Foss is at E.M.I. Electronics Ltd., Telemetry Division.

Page 220 — "Seismic Telemetry System Over Power Line Carrier" by P. A. Watt

Mr. Watt is Senior Research Fellow, University of Tasmania.

Page 273 — "A Multichannel High Speed Film Recording System" by H. A. Richardson.

Mr. Richardson is at Associated Electrical Industries Ltd., Military Radar Engineering Department.

Page 354 — "The Design of Electro-Mechanical Multiplexing Switches for Airborne Applications" by A. J. Helliwell and P. H. Pardey.

The authors are with S. Davall and Sons Ltd.

Page 362 — "Application of 465 Telemetry System to Event Marking" by A. H. Ellis.

Mr. Ellis is at E.M.I. Electronics Ltd., Telemetry Division.

Page 400 — "Minimum-Error Demodulation of Binary PCM Signals" by Earl F. Smith.

Dr. Smith is Principal Research Engineer, Advanced Communications Group, Radiation Inc.

Page 478 – The author of Reference 14 should be Barker R. H. not Barker S. N.

Page 488 — "Multi-Threshold Digital Data Transmission Systems, Their Advantages and Possible Operational Modes" by A. Brothman, M. W. Gomery, S. J. Halpern and A. H. Miller.

The authors are with Transitel International Corp.

General Information

The Conference Office, at which all enquiries relating to the Conference should be made, will be open from 9 a.m. on each day of the Conference.

All enquiries relating to the Conference before the 23rd September, should be addressed to the Honorary Secretary and Treasurer of the Conference, c/o The Institution of Electrical Engineers, Savoy Place, London, W.C.2. The telephone number is Covent Garden 1871.

The text of each formal paper included in the Convention programme is reproduced in this booklet. All items in the programme will be presented by a rapporteur. Opportunity will be provided for discussion of all the programme material.

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Programme

PARTICIPATION IN DISCUSSION

Participants wishing to be called upon by the Chairman to take part in any of the discussions at the Conference are asked to notify the Honorary Secretary and Treasurer before or during the Conference, indicating the Session or Sessions in which they wish to be called.

OPENING CEREMONY

3.30 p.m., Monday, 23rd September, 1963

Immediately followed by

SESSION 1: INTRODUCTORY

Pages 6—20

WILFRID J. MAYO-WELLS — Lecture on 'The Art of Telemetering—The Path to Maturity'

P. F. GUNNING — 'Thirty Years of "Grid" Telemetering'

BERNARD N. GORDON — 'Has the Telemetry Technology Approached Maturity?'

6.30 p.m. COCKTAIL PARTY

at the Institution of Electrical Engineers, Savoy Place, London, W.C.2

SESSION 2: 9.30 a.m., Tuesday, 24th September, 1963

'INDUSTRIAL SYSTEMS'

Pages 21—99

AUGUSTUS C. JOHNSON, C. FRANK RILEY, Jr., WILLIAM E. FLOWERS, RICHARD K. HOVEY, PHILIP YAFFEE, FRED STARBUCK, JAMES W. BAILEY, and CLIFFORD W. SCOTT — 'An Integrated System for Collection and Analysis of Environmental Test Data'

F. VINTON LONG — 'High Speed Telemetering for Supervisory Control of a Long Pipeline'

M. K. KINGERY — 'Data transmission Inside Large Space Environmental Chambers'

K. U. BOLWELL — 'Telemetering of D.C. Voltage Values over a Microwave Link System'

H. J. WARD and H. B. CHATTERJI — 'Remote Phase Comparator'

D. H. JONES — 'A Multichannel Contactless Telemetering System for Vibration Studies on Steam Turbine Blades'

D. G. FROGGATT and T. SKWARA — 'Intrinsically Safe Time Division Multiplex Telemetry System for Use in Coal Mines'

G. M. CAHEN, H. E. GUILLERM and J. J. SCALABRE — 'New Methods of Data Transmission for Electric Power Networks'

SESSION 3: 2.15 p.m., 24th September, 1963

'TRANSDUCERS AND SIGNAL CONDITIONING'

Pages 100—169

SESSION 4: 6.00 p.m., 24th September, 1963

'GEOPHYSICAL AND BIOMEDICAL SYSTEMS'

Pages 170—230

SESSION 5: 9.00 a.m., Wednesday, 25th September, 1963

'RECORDING AND DATA PROCESSING'

Pages 231—306

B. O. HICKS	'Telemetry Facilities of the Pacific Missile Range, U.S.A.'
J. C. HUNG	'Double-Reception Discrete Data Optimum Continuous Signal Recovery'
H. B. RIBLET and J. P. RANDOLPH	'Satellite Telemetry and Data Processing'
G. H. SCHULZE	'Time Displacement Errors in Instrumentation Tape Recording'
H. A. RICHARDSON	'A Multichannel High Speed Film Recording System'
E. S. MALLETT, R. E. PERKINS and H. W. P. KNAPP	'A Telemetry Data Processing Equipment'
A. P. WILLMORE	'The Automatic Analysis of Telemetered Data'

12.20 for 1.00 p.m. CONFERENCE LUNCHEON

at the Connaught Rooms, Great Queen Street, London, W.C.1

SESSION 6: 9.30 a.m., Thursday, 26th September, 1963

'MODULATION, CODING AND MULTIPLEXING'

Pages 307—374

H. INOSE, Y. YASUDA and H. TAKANO	'Video Transmission by Delta-Sigma Modulation'
F. A. GICCA	'Optimizing Space Television Transmission'
J. C. HANCOCK and H. SCHWARZLANDER	'On the Usefulness of Signal Design Techniques in Adaptive Telemetry Links'
J. E. MEDLIN	'The Comparative Effectiveness of Several Telemetry Data Compression Techniques'
S. KARP and P. K. HIGUCHI	'An Orthogonal Multiplexed Communication System Using Modified Hermite Polynomials'
A. J. HELLIWELL and P. H. PARDEY	'The Design of Electro-Mechanical Multiplexing Switches for Airborne Application'
A. H. ELLIS	'Application of Telemetry System Type 465 to Event Marking'
P. N. SARGEAUNT	'A Simple Supervisory Encoder Using Pulse-Length Modulation'

SESSION 7: 2.30 p.m., Thursday, 26th September, 1963

'ERROR DETECTION, DEMODULATION AND SYNCHRONIZING
(including Random Sequences)'

Pages 375—437

7.00 for 7.30 p.m. CONFERENCE BANQUET

at the Grosvenor House, Park Lane, London, W.1

SESSION 8: 9.30 a.m., Friday, 27th September, 1963

'AEROSPACE SYSTEMS'

Pages 438—524

Session I—Introductory.

THE ART OF TELEMETERING—THE PATH TO MATURITY

WILFRID J. MAYO-WELLS

Synopsis.—The organization of an international conference devoted in its entirety to the consideration of telemetering heralds the achievement of maturity by this universally practised art. It is the aim of this brief account to delineate the long struggle for recognition, to explain the diversity of the two main branches created, and so to afford a common background for the discussions of this meeting.

Tracing the history of national conferences on telemetering held in the United States, it is shown that the exigencies of military security and urgency resulted in the division of the national effort into two groups, namely those engaged in industrial, and in military, applications. How the reunion between these two rival factions was achieved is described, and the growth to national recognition explained. Highlights in the development of both wire-linked and radio telemetering, from the earliest beginnings, are followed by a discussion on the definitions and philosophy of each type. The points held in common, and the major differences existing between the present-day requirements of 'Aircraft/Missile/Ordnance' and 'Industrial' telemetering are discussed with particular attention being paid to terminology and principles. Some of the more popular systems are mentioned in brief detail, and the lecture ends with a short discussion on reliability.

Mr. Mayo-Wells is at Vitro Laboratories, Silver Spring, Maryland, U.S.A.

THIRTY YEARS OF "GRID" TELEMETERING

By P. F. GUNNING

Summary.—Various telemetering systems used over the last 30 years to control the British grid are briefly described in chronological order showing how each contributed to the needs of the moment and to the trend of development towards the high capacity multiplex systems of today. Some design features of the Generating Board's latest telemetering system, at present being developed, are described.

Introduction.—Telemetering in the electricity supply industry is probably as old as power system interconnection. Thirty years ago, in the then Central Electricity Board's grid control centres, simple telemetering systems[1, 2] were used to indicate the individual power transfers between the independently owned 'selected' generating stations and the associated high voltage 'grid' stations.

Telemetering Signalling Channels.—The design of telemetering equipment for the British grid has always been influenced by the available bandwidth of the bearer telephone circuits. Circuits rented from the Post Office were first used by the Central Electricity Board in the early 30's[2] and today are used exclusively by the Generating Board for grid control communications, telemetering and general indications, and also to a great extent for the supervisory control of unattended grid stations and for feeder protection[5, 6]. Although power line carrier is used extensively over the whole country for feeder protection up to the limits set by channel congestion and economy consistent with security, power line carrier in Britain is rarely a practical proposition for grid control services except in the north of Scotland. Radio is used for mobile services and is permitted in an emergency between fixed 'listening-out' installations at major stations.

In the early 30's the bandwidth of most rented circuits was only 2 000 c/s and consequently the earliest telemetering systems had to be 'on demand', 'speech interrupted' or 'below speech continuous' (i.e. below 300 c/s). D.C. earth-return phantom signalling, which does not interfere with speech was used for telemetering when its use was permitted from high-voltage grid stations in 1945.

In the mid 30's, when continuous telemetering of power transfers between neighbouring control areas was required (1935), circuits with a bandwidth of 2 500 c/s were becoming available. By filtering off speech frequencies above 2 000 c/s, the spectrum between 2 000 and 2 500 c/s was used to provide two 'above speech' continuous telemeter signalling channels.

At the present time (1963) the generally available bandwidth of 3 kc/s is adequate for the simultaneous transmission of speech plus six 50 baud signalling channels, but it is unlikely that there will be any expansion of the available bandwidth in the future. The demands on these six channels are very heavy; some stations require 40 telemeters (four channels) as well as channels for data transmission, automatic control and system protection.

Telemeter Response Time.—Automatic frequency control permits independently operated power systems to be integrated into large power pools. It enables each system to satisfy its own load variations automatically thus preventing the overloading of comparatively weak power lines linking independent systems.

Automatic frequency control requires quick response telemetering to detect off-target errors and to make corrections promptly to generation plant otherwise hunting or load swinging results. With more than 200 power stations in one compact system of 32 000 mW under national control and with no a.c. power connection to the mainland of Europe, there has been no need for automatic frequency control in Britain[3].

Being in the fortunate position of not having to provide quick response telemetering, in 1952 a response time of 15 sec was adopted as standard for feeder flow telemetering although times up to 2 min had proved to be satisfactory.

Multiplex Transmission.—By 1945, to meet the demands for more telemeters from individual stations, the time had come for telemetering systems which monopolized expensive signalling channels to be superseded by multiplex systems which catered for a number of telemeters on one channel[7].

With a response time of 15 sec it was possible to use ordinary watt-hour meters with slow impulse rates and 10-way time division multiplex transmission over 50 baud signalling channels. The development of this 'standardized system' (1952) resulted in a reliable and comparatively inexpensive countrywide telemetering network which has been continually extended and re-routed to keep pace with grid expansion.

Mr. Gunning is Telecommunication Engineer, Central Electricity Generating Board.

In 1961 an appraisal was started of probable future demands, together with an examination and evaluation of contemporary telemetering and data transmission philosophies. This appraisal indicated that there was no basic need for a faster response time than that provided today (largely because there is no need for automatic frequency control), but the real need was for a greatly increased data handling capacity to cater for a greater variety of low volume data sources. Axiomatically this could only be achieved by increasing the bandwidth or decreasing the speed of response, or improving the efficiency of transmission.

It was decided to retain the existing bandwidth (120 c/s) and to provide a response time that was graded according to the importance of the service.

This appraisal lasted two years and the conclusions have led to the development of a digital transmission systen using pulse code modulation which differs little in principle from the 'coded impulse count' system which first appeared in 1945 but uses a faster signalling speed and modern solid state switching techniques.

The new system is known as the Mk II Standardized System.

Development 1932–1963.—The first telemetering systems mostly operated 'on demand', the readings being requested from time to time by the grid control engineers.

(*a*) In one system the interval between the 'request' signal and the 'repiy' signal from the station determined the deflection of a motor-driven pointer. This time duration position signalling system was basically unsound since it relied on the power system to remain intact to keep synchronous motors at the remote stations in step with synchronous motors at the control centre;

(*b*) in two analogue-to-digital position signalling systems, the receipt of a 'request' signal clamped a wattmeter pointer which made contact with one of a number of insulated studs let into the scale or the equivalent. A stepping uniselector then searched for the 'marked' stud and sent an impulse to the control centre for each step of the uniselector. Responding to these impulses a uniselector at the control centre rotated a pointer in one system, and in another system controlled the deflection of a milliammeter;

(*c*) in another analogue-to-digital position signalling system, a servo-motor moved a carriage with 'high-low' limit contacts over the scale of a wattmeter until contact with the meter pointer was broken, meanwhile sending 'increase' pulses to the control centre appropriate to the amount of movement. The 'reading' was continuous until released by the control engineer, the carriage moving up and down following the power flow variations under the control of the servo-motor and sending 'reduce' pulses as the carriage moved down to clear the pointer. A bothway stepping mechanism at the control centre rotated a pointer in response to the 'increase' and 'decrease' pulses.

In addition to these 'on demand' systems there was also a 'continuous' system similar to (*c*) which, when the line was not in use for speech, transmitted a coded impulse train to the control centre after each movement to indicate the new position of the carriage. This electro-mechanical position signalling telemetering system generated signal trains continually and consequently required a lot of maintenance.

1935.—With the need for 'continuous' indication of the power flows between neighbouring grid control areas, the 'on demand' telemetering systems were outmoded by quick response 'phototelemeter' and 'variable frequency' telemetering systems. By restricting the speech band these systems were able to use the same channels as the telephone system without interference.

The 'phototelemeter' was essentially a rotating optical system which, 2–5 times a second depending on the arrangement, repeatedly scanned a mirror which was progressively unmasked by a wattmeter as its pointer moved towards dull scale. An 'above speech' voice frequency signal (above 2000 c/s) was sent to the control centre each time the scanning light beam was reflected by the mirror into a light cell. The 'tone on, tone off' variable pulse ratio signal so generated was reproduced at the control centre as a recurring impulse of variable duration to deflect the pointer of a damped d.c. instrument; the response time was about 1·0 sec.

The 'phototelemeter' remained in service for nearly 20 years. There was more than one arrangement; the popular model had a variety of serrated combs which could be placed on the mirror to interrupt the rotating light beam at the required frequency. This mechanical tone generator was trouble-free except when the signal frequency, which varied with system frequency, ranged beyond the acceptance of the tuned receivers during critical system conditions.

In the 'variable frequency' system, a wattmeter rotated a variable capacitor to vary the frequency of a 'below speech' signal tone (below 300 c/s). At the control centre this tone was amplified, clipped and fed through a filter to a rectified indicating instrument. The filter attenuated the tone completely at the frequency corresponding to 'scale zero' but progressively allowed more to pass as the tone frequency rose to the value corresponding to full scale deflection.

This frequency modulated system was successful although routine adjustment was necessary to correct drift and as the response was not linear summation was difficult.

1937.—In 1937 an 'impulse count' telemetering system was introduced; this was a simple 'pulse-rate' system, accurate and easy to maintain, and was in widespread use over the next 20 years. Impulses generated by watt-hour meters were transmitted to the control centres where they were counted in binary fashion on telephone relays. At regular intervals clock pulses transferred the binary counts to 'display' relays and restored the counting relays which then proceeded to count the next integration of impulses. Each binary 'display' relay connected an appropriately graded constant current to its associated indicating instrument.

Two watt-hour meters were used for each reading, one to generate short impulses for 'import' transfers, and one to generate long impulses for 'export' transfers. At the control centre a pulse length detector controlled the polarity of the constant current. Net summation import/export indication was obtained by returning the circuits of the individual telemeter indicating instruments through a summation indicating instrument to the mid-point of the constant voltage supply.

The 'impulse count' system with its integrating periods of 30 sec or more, depending upon the impulse rate, demonstrated that there was no need to provide quick response telemetering for the manual control of a large independent grid system.

1939.—'Slotted disc' telemetering was introduced in 1939. This was a quick response telemetering system which generated an 'impulse rate' signal by interrupting a light beam by means of slots in a disc rotated by a watt-hour meter. At the control centre capacitors, charged from a constant potential, separately discharged into an indicating instrument at the 'on' and 'off' of each impulse of signal tone. This was a satisfactory system for unidirectional power transfers but was never developed for 'import/export' readings because of the necessity to exert a torque, constant under all conditions, on the shaft of the watt-hour meter equivalent to the zero import/export impulse rate.

1945.—Three systems were introduced in 1945.

The first was the 'synchro-pulse' system in which d.c. earth phantom signal impulses, polarized to discriminate between 'import' and 'export' transfers, were generated by watt-hour meters. At the control centre the impulses adjusted the supply to a watt-hour meter step by step until it generated impulses at the same rate as the signal impulses. In its simpliest form the telemeter indication was a reading of the power consumed by the local watt-hour meter. This 'pulse-rate' system was popular for a time in one of the control areas; it had a rapid response but was slow to attain maximum accuracy.

The second system was the first real attempt at transmitting more than one continuous reading over a single telemeter signalling channel. In this all-relay 'pulse-rate' multiplex system, which lasted for 10 years, a coded signal train of five impulses was transmitted whenever an impulse was generated by any of four watt-hour meters. The first impulse in the train served as a start signal, the other four impulses were successively associated with the four watt-hour meters; each was of short duration but was lengthened if the corresponding watt-hour meter had impulsed. At the control centre the coded trains were decoded and pulses corresponding to the lengthened impulses were delivered to the appropriate impulse counting groups (1937).

System three, the 'coded impulse count' multiplex system, catered for eight slow pulse rate telemeter readings over a single impulsing channel; many more could have been transmitted but the electro-mechanical multiplex equipment would have soon worn out. At the outstation the various watt-hour meter impulses were separately counted over separately time displaced integration periods as required ($1\frac{1}{2}$, 3 or 6 min). The corresponding 'display' counts (1937) were transmitted in turn, each in less than 2 sec as pulse lengthened binary coded signal trains complete with identification ('address') codes and import/export intelligence. These trains were decoded at the control centre and the binary 'display counts' transferred to the appropriate telemeter display relays selected by the 'address' code. Each binary display relay connected an appropriately graded constant current to the associated indicating instrument (1937), the polarity being controlled by the import/export intelligence.

1946.—Three systems were introduced in 1946.

The first was the now popular electronic 'cup and bucket' telemeter system[4]. Almost trouble-free, this slow 'pulse-rate' system was simple, accurate and had a faster response than the 'impulse-count' system for the same impulse rate. Impulses from a watt-hour meter were transmitted to the control centre where a capacitor (the 'cup'), charged from a constant potential, emptied at the 'on' and 'off' of each impulse into a reservoir capacitor (the 'bucket') connected across a high-gain amplifier. The amplifier output through a smoothing circuit to a cathode follower applied feedback to neutralize the input and fed an average potential to an indicating instrument; balance was established when the voltage across the instrument was proportional to the impulse rate. The smoothing circuit normally had a long time constant which automatically shortened whenever the 'pulse-rate' changed. The connections to the instrument were reversed on receipt of export impulses. The 'cup and bucket' telemetering system was standardized by the British Electricity Authority in 1952[6] and more than 2 500 are now in use throughout the country.

System two, the 'teleprinter code' multiplex system, was the first successful attempt to transmit in almost 'real-time' six or more different watt-hour meter impulses over a common signal channel[4]. In this all-electronic system, standard 'start-stop' 7-bit teleprint characters identified different watt-hour meters and were separately transmitted whenever the corresponding watt-hour meters impulsed. At the control centre each teleprint character was decoded and reconstituted as a watt-hour meter impulse and fed into the corresponding 'cup and bucket' telemeter receiver (1946). As the transmission time for a 7-bit character at 50 bauds was only 0·14 sec, the occasional time displacement of characters waiting to be transmitted did not affect the telemeter receivers. Although so far the the British Electricity Authority was concerned this system was succeeded in 1952 by the standard 'pulse-rate time-division' multiplex system, it was and still is a successful telemetering system.

System three, a 'coded torque balance' multiplex system, was introduced in an attempt to conserve channel carrying capacity by signalling reading changes only. This system was not a success; the heavy signalling traffic it produced was unexpected and wore out the electro-mechanical equipment.

In this short-lived but sophisticated position signalling system the torque of a wattmeter was balanced by the torque produced by a moving coil energized by d.c. from a counting group which automatically reduced or increased its count to keep the torques in balance. Each revision of count was signalled to the control centre in binary code together with an 'address' code. The subsequent decoding and display at the control centre was similar to the 'coded impulse count' multiplex system (1945).

1947.—An electronic variable 'pulse-width' generator was introduced to 'telemeter' 'amps' but it was not produced in quantity as the operation engineers preferred to continue with power readings. In this static system, the continuous 'tone-on, tone-off' variable pulse ratio signal actuated a 'photo-telemeter' receiver (1935) at the control centre.

1948.—A 'coded balance' position signalling multiplex system was introduced in 1948. Using Midworth self-balancing transducers with servo-mechanical coding to initiate 'above speech' binary signal codes, it was used in one of the control areas until superseded by the standard 'pulse-rate time-division' multiplex system (1952).

A cyclic 'pulse-width' multiplex system for readings of 'amps' was successfully demonstrated in 1948 but did not go into service as the operational requirement had meanwhile changed back to readings of 'watts'. In this system clock impulses were transmitted once a second to step a 'reading selection' relay train at the outstation which returned an impulse before the incidence of the next clock pulse after a time proportional to the selected reading.

At the control centre each telemeter was a valve voltmeter, the reading being held by the charge on two capacitors in parallel, one large and one small. The large capacitor was disconnected and discharged when the corresponding clock impulse was transmitted and was constant current charged in the time interval between the reply pulse and the next clock pulse when it was re-connected to correct the reading of the valve voltmeter.

1952.—When the electricity supply industry was nationalized in 1948, the British Electricity Authority co-operated with leading telephone manufacturers specializing in 'grid' telemetering equipment[6]. and in 1952 adopted as standard an electronic start-stop 'pulse-rate time-division' multiplex system[4, 7]. In this system the impulse contacts of 10 watt-hour meters were successively scanned in 20 ms steps by a 10-way time-division coder-sender every 300 ms or so. At the control centre a 10-way time-division decoder reconstituted the meter impulses and directed them to the appropriate 'cup and bucket' telemeter receivers (1946).

With more than 2 500 pulse-rate 'cup and bucket' telemeters and 300 time-division multiplex equipments in operation, this 'standardized system' has superseded all other telemetering systems previously used to control the grid. It is a thermionic electronic system with cold cathode switching and slow rate impulsing ($66\frac{2}{3}$ impulses a minute for full scale deflection) from watt-hour meters. It is economic in cost and channel requirement, accurate, and easy to maintain. The initiating intelligence, the watt-hour meter impulse, is preserved in one form or another throughout the system and is readily relayed ('patched') on demand between control centres.

The watt-hour meters used with this standard multiplex system have three 'make' contacts which operate in succession 'abc' for clockwise (import) and 'cba' for anti-clockwise (export) rotation[4, 7]. A relay, which operates when 'b' is contacted after 'a' and releases when 'b' is contacted after 'c', controls over an independent signalling system using the same line, the operation of a corresponding relay at the control centre to reverse the pointer deflection.

Time-division multiplex transmission equipment is only provided at major stations. These major stations collect 'pulse-rate' signals from nearby minor stations. For this purpose simple electro-mechanical multiplex equipment is provided, sufficient for two readings with long impulse (90 ms) discrimination for one reading and short impulse (45 ms) discrimination for the other[7].

1961.—A modern solid-state wrapped-joint version of the standard 'time-division' multiplex system was introduced in 1961, complete with its own signalling system for individual watt-hour meter import/export intelligence. Added to the 10-bit time-division scan, an eleventh 'bit' transmits sign intelligence appropriate to each meter in turn; the ten signs being sent in ten successive time-division scans. Synchronizing is obtained by a pause after each cycle of ten transmissions. This solid-state system is used to relay selected telemeter 'impulse-rates' from the area grid control centres to the national control centre in London, and also to relay, from impulse generators, readings which are the summation of a number of telemeter readings such as 'total generation' or 'area net transfer'. These impulse generators were introduced in 1953[4, 7]. D.C. from the output potentiometer of a summation indicator-recorder at the grid control centre is balanced by integrated current obtained from impulsing continuously generated at a rate proportional to the d.c.

1963.—A simple slow-rate 3-way 'pulse-code' multiplex system, a mixture of solid-state and electro-mechanical construction, has been introduced for use between minor stations and major collecting stations. In this system a single impulse is transmitted for each impulse generated by the first watt-hour meter, two for the second, and three for the third watt-hour meter.

Mk II Standardized System (1964/5).—The Mk II Standardized System is a large capacity telemetering system which will transmit groups of up to ten telemeter readings as successive cyclic 'addressed' paragraphs, each paragraph of ten readings being transmitted in 3·3 sec with 100 ms gaps between paragraphs. The Mk II Standardized System is also a large capacity 'miscellaneous data' transmission system which will transmit 'addressed' paragraphs containing up to 30 numerical figures also in 3·3 sec, Data paragraphs will only be sent when required and in order of priority, and will be interlaced singly between telemetering paragraphs. Telephone calls, circuit breaker indications, and statistical information will be treated as 'miscellaneous data'.

The Mk II Standardized System has not yet reached the production stage; the main features of the new system so far as they concern telemetering are as follows:

(*a*) Asynchronous transmission has been adopted with 25 c/s amplitude modulation of the signal carrier to synchronize 'bit' stepping during paragraph transmission. For 'bit' intelligence (i.e. mark or space) the signal carrier will be frequency modulated in step with the 25 c/s amplitude modulation at 50 bauds. The 25 c/s amplitude modulation will be removed for 100 ms between paragraphs to synchronize paragraph start'.

(*b*) Intelligence will be transmitted in paragraphs containing up to 11 'words' with no spacing between words, each 'word' of 300 ms being of fifteen 20 ms 'bits' coded 'two-out-of-five three times'. The first word will be the 'address', the second word will be the first telemeter reading, and the third word will be the second telemeter reading, and so on.

(*c*) Each word of 15 bits will be marked 'two-out-of-five three times' to code any number from 000 to 999, thus there is capacity for 1 000 differently addressed paragraphs but only 100 will be used.

(*d*) With the reduction to 100 addresses, the first 5 bits of the address word will have the same 'two-out-of-five' marking. Taking advantage of this by 'marking' bits 4 and 5 there will be ample time (60 ms) for the effects of any 'first impulse distortion' at the commencement of the 25 c/s bit stepping amplitude modulation to have disappeared before any f.m. bit marking is transmitted.

(*e*) By sending each telemeter reading as a 'code 3-figure word' in 0·3 sec, better use will be made of the 50 baud telemeter signalling channels than with the standard 'pulse-rate time-division' multiplex system; 40 readings compared with 10 for the same response.

(*f*) At the control centre each word will be decoded and stored on a set of 15 miniature relays, 1 per bit until corrected when necessary by the cyclic transmissions. Relay rather than solid-state storage was chosen to provide an active store with isolated parallel outputs. To avoid battery drain and the problems of heat dissipation the storage relays will be of the permanent magnet locking type.

(*g*) One of the functions of these display storage relays will be to switch graded constant currents to moving coil projection type numerical indicators. When energized by graded constant currents of opposite polarity these indicators will also display miscellaneous annunciations.

(*h*) The analogue-to-digital converter will be successively connected to the associated transducers by 2-pole reed relays.

(*i*) To simplify summation and/or display at the control centres the analogue-to-digital converter will count directly in mWs, mVars, amps, volts, or system frequency by means of scaling resistors in the output circuits of the transducers.

(*j*) The analogue-to-digital converter will count in 'two-out-of-five' code and each 'coded count' will be a 3-figure reading which can be as accurate as 0·1% for the largest reading 999, but this is unrealistic since the inherent errors of presently available high voltage metering transformers, transducers, and analogue-to-digital converters are probably not less than 0·3%.

(*k*) The analogue-to-digital converter will have a long-term accuracy better than 0·3% with reference to full count (999). It will employ reed relays to switch successive balancing steps. Although accuracies of 0·1% are probably attainable in laboratories it is doubtful if this can be maintained over long periods in unattended installations at an economic cost.

(l) The analogue-to-digital converter will code import/export intelligence as 'odd' counts for import and 'even' counts for export power transfers. This intelligence will be indicated by lamps or coloured lights in the projection indicators (*g*) switched by the storage relays (*f*).

(*m*) By using error-detecting codes (two-out-of-five) throughout the system and digital display of intelligence there will be no loss of accuracy either from transmission or display.

(*n*) Torque balance polyphase watt-metric transducers will be used with bi-polar d.c. linear output 0–10 mA (with 25% overload capacity), the polarity $-ve$ or $+ve$ depending upon direction of power flow. The d.c. output will also be available for local indicating instruments at the outstation.

(*o*) System frequency transducers with coded 'two-out-of-five' output accurate to 0·002% (i.e. ·01 c/s at 50 c/s), using almost successive 10-sec counts of the 10th harmonic of system frequency are being developed.

Conclusion.—Successful telemetering systems for the electrical supply industry are rarely profound in design. Perhaps because of this, they provide reliable service over many years from unattended stations with the minimum of maintenance and particularly in emergencies when the power systems they serve are in a critical condition. But this is not enough, a successful telemetering system must be miserly in its use of even the cheapest communication channel which by comparison is expensive and, with its transducers and with its display instrumentation which has to be acceptable ergonomically to the operating engineers, must be cheap enough to justify its provision on a large scale.

Many ingenious power system telemetering systems have been developed in different countries for different applications under different conditions. The various systems described in this paper were developed to meet changing operational requirements of the British grid over 30 years and to suit the signalling channels available. Notwithstanding the standardization of telemetering equipment for the British grid since 1952 the evolution of new systems shows no signs of diminishing.

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HAS THE TELEMETRY TECHNOLOGY APPROACHED MATURITY?

By BERNARD M. GORDON

Summary.—After a decade of intensive development, telemetry engineering is now beginning to achieve the status and respect due as a prime necessity in space technology and industrial automation. The breadth of experience and technique development now available to the telemetry system engineer provides the foundation for increased scopes of functional utility. The requirements ahead are formidable and challenging. The successful accomplishment of these tasks will demand the exercise of considerable engineering judgment and will, of necessity, force the ultimate maturing of the telemetry technology so that it can face the inevitably increasing demands for information from a distance with assurance and foresight.

Introduction.—The question posed by the title of this paper is intended to open the door to discussion related to some probable future developments in the telemetry fields of endeavor. Telemetry today, after a decade of rapid growth of the industry, has achieved recognition as a primary technological area of accomplishment. The reliable and accurate acquisition of information from a distance has turned out to be one of the most challenging and formidable of electronic engineering tasks. Lately, however, there appears to be whispered implication that the telemetry art has so matured that there is relatively little need for additional advancement and that the tasks ahead may be but routine engineering adaptations and/or improvements of what has already been achieved.

Contrarily, it is felt that the telemetry industry, now having proven that reliable data acquisition is possible, has merely reached a state of adolescence and that maturity still awaits beyond the future application and development of more sophisticated communication, 'adaptive' control, selective data acquisition and real-time information usage system engineering techniques.

Before proceeding, it should be stated that the last decade has seen significant advances in circuit design and packaging of telemetry equipments, and in the adaptation of digital approaches. It is probably true that the design of highly accurate measurement circuits that must survive extremes of temperature, shock, vibration and operational handling, represents more difficult tasks than are common. As a corollary, the vehicular packaging attained by telemetry-oriented organizations also represents superior achievement.

Ten years ago, telemetry was not yet accepted as being one of the primary, necessary functions. Early telemetry efforts, more often than not, were crude, albeit clever, equipments hastily developed under duress when it was finally realized that certain measurements might have to be taken. Little was really then known or understood by those engaged in the telemetering practice of the fine points and limitations imposed by communication and sampled data theory, the tolerances of precision componentry and the pitfalls of field application and maintenance.

Catalyzed to a large extent by the more sophisticated needs of the early missile programs, it became increasingly apparent to telemetry users at the beginning of the past decade that more accurate acquisition of larger quantities of data was required. Even more important was the need to reduce the time delay between initial data acquisition and ultimate information availability. The decade saw considerable developments oriented toward the achievement of these ends (Fig. 1). The growing acceptance of computer technology and design practices at the beginning of the decade and the availability of solid state componentry toward the middle of the decade accelerated the required developments. However, although the telemetry field may be thought of as encompassing transducers, including excitation, signal conditioning, multiplexing, coding and/or keying, modulation, transmission, reception, primary ground conversion, recording, display and end use functional linkage, the majority of developmental effort in the past period has been directed toward signal conditioning, coding and keying, primary ground conversion and recording. Relatively little effort has been directed by those actually engaged in the design and manufacture of telemetry equipment toward measurement technique, data redundancy assessment and reduction, adaptive selection, transmission and reception, and ground real-time usage and control.

In the specific areas developed, however, much has been accomplished. One may recall that a decade ago it often took as long as six to nine months from the time of raw data acquisition to computer print-out as compared to, if need be, several seconds now. Expected accuracies have improved from several per cent to an order of magnitude better. The adaptation of computer-oriented

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techniques, the increasing interest and applied efforts of broad-background engineers in the telemetry field, and the availability of reliable semiconductor componentry, as well as an increasing understanding of failure mechanisms, have wrought the improvements achieved.

The growth from early infancy to more recent adolescence may be traced from the early missile data reduction systems, through the first applications of high-speed analog-to-digital conversion, resulting in direct computer-linked data reduction, the development of band switching and high accuracy discriminators (including phase lock discriminators) with their improved conversion and filtering techniques, the development of the double-buffered computer real-time tape preparation units, and the first concepts of early vehicular pulse code modulation systems. The next few years saw considerable painstaking engineering work yield the realization of practical and reliable circuitry culminating in the now well-publicized achievements of low level, multiple channel p.c.m. telemetry such as are used on Titan II, Minuteman and Telstar, and the acceptance of reliability requirements such as have been demanded for Gemini and Apollo. The same period has also seen the beginnings of the application of these techniques in industrial areas such as monitoring and mapping of atomic reactor temperature levels, bio-medical usages for high-speed mapping of brain wave potentials, patient monitoring in hospitals, meteorological applications, and many more.

The successful development of new types of reliable and accurate signal switching and coding circuitry has been a primary factor in the gaining of status for telemetry engineering endeavors and applications. However, there still exists at this time considerable knowledge and techniques derived from other electronic practices which have not yet been brought to bear in the telemetry field. Some of the techniques which have been conceived and developed for the communications field, automatic control field, combat information centers, etc., have considerable significance with respect to future telemetry requirements, and do not as yet reveal themselves in present designs of major telemetry equipments. Some of these relate to:

1. Further refinements in the application of sampled data theory as applied to multi-channel systems
2. Application of more sophisticated correlation techniques for greater signal/noise enhancement
3. Self-adaptive bandwidth control techniques
4. Beacon transponding techniques
5. Closed loop selective interrogation techniques
6. More sophisticated synchronization data coding and data recovery techniques.

To a large extent, many future developments, only a few of which are to be listed and discussed, will place primary emphasis on system engineering design concepts rather than new basic circuits. Stated another way, the telemetry field is now emerging from a state of development of numerous useful circuit building blocks, both analog and digital, which have now been reasonably well proven and which, of course, will continue to be refined. Now these in combination with other techniques which have been developed in some of the other fields previously enumerated, as well as some new circuits and techniques yet to be developed, provide the basis for greatly extending the capabilities and scope of telemetry equipment.

Some of the areas considered to be most fruitful for further development include:

1. Improved coding and synchronizing techniques
2. Hybrid coding/modulation systems
3. Self-healing vehicular data acquisition systems
4. Nanowatt telemeters
5. Adaptive bandwidth systems
6. Data redundancy reduction techniques
7. Coherent data-rate carrier frequencies
8. Interrogation control (vehicle-initiated)
9. Interrogation control (ground-initiated)
10. Transducer and parameter representation advances
11. Spectrum extensions
12. Telemetry repeaters
13. Telemetry-control communication interrogation
14. Network transducers
15. Real-time display and information mapping
16. Multi-dimension integrated componentry.

Each of these areas will be discussed very briefly.

Improved Coding and Synchronization Techniques.—Considerable work yet remains to optimize the amount of data that can be recovered from a given signal/noise situation. Particularly, attention should be paid toward balancing recovery of data *per se* under given conditions against being able to synchronize under those same conditions. At the present time, synchronization is often the limiting factor. (Related to this area, techniques recently developed for other communication systems, such as the duo-binary coding system, should have application in many telemetry situations). There is room for considerable study and investigation so that balanced probabilities for both synchronization and data recovery may be obtained.

Hybrid Coding/Modulation Systems.—The past period had seen a competition between p.c.m. and some of the older techniques, including p.d.m., p.a.m. and continuous f.m. modulation systems, with p.c.m. increasingly becoming more acceptable. However, many data usage requirements exist where a combination of techniques within a single system may be desirable. Useful work may be directed toward establishing a standard but variable format wherein p.c.m. and p.a.m. may be inter-mixed for such techniques as p.a.c.m. on which considerable preliminary work has already been done. There exists at this time no basic deficiencies in technology with respect to basic coding circuitry or modulation technique to obviate the ability to define a generally useful format capable of handling considerable quantities of wideband data at lower accuracy and narrow-band data at higher accuracy.

Self-Healing Vehicular Data Acquisition Systems (Fig. 2).—Most telemetry systems built to data, with a few exceptions, have followed what might be called a straight-through design, with one element feeding sequentially into the next. As the requirements for greatly extended mean time between system functional failures are increased, more complex system structures of the self-healing, self-substituting type may become applicable. As has been demonstrated elsewhere, this type of system organization is potentially capable of yielding vastly improved system functional, continued performance even in the event of sub-unit failure. Means need to be developed for determining failures in a simple manner and effecting circuit switch-over. There is considerable room for cleverness here. The optimal design of this type of system will require a real systems engineering approach combining the best available talents of the circuit designer, the system user, the reliability engineer and the mathematician (parenthetically, it is not clear to the writer whether slow time per Einstein's theory applies to the mean time to failure ? ?).

Nanowatt Telemetry.—As mentioned previously, it is expected that new types of componentry will find ready application in presently existing types of circuits and systems. However, certain new types of components just becoming available, and those as yet unforeseen, could bring about the feasibility of entirely new types of systems. For example, the insulated gate field effect transistor recently announced makes possible such significant decreases of power consumption in both analog and digital circuitry as to greatly extend the possible application of telemeters.

Adaptive Bandwidth Systems (Fig. 3).—It is expected that future telemetering may have a provision built in for changing the rate of data transmission dependent upon a number of factors. These factors might include the occurrence of specific events in the vehicle, the determination of unexpected signal interference resulting in signal/noise ratios intolerable to the ground receiving equipment or pre-programmed sequences. Either under vehicular program control or under control of a command code transmitted from the ground equipment, the telemetry and its communication link may thus actually increase the amount of information received by decreasing the amount of data transmitted.

Data Redundancy Reduction Techniques (Fig. 4).—Much of the data presently being transmitted contains no real information. That is, it is not changing rapidly enough to require each measurement to have new significance. On the other hand, the possible rate of change of data or bandwidth may be such that high sampling rates within a fixed program are required to avoid the possibility of frequency folding. The elimination of redundancy in the data transmitted (i.e. a relative increase in the information contained) may be achieved by adding memory to the vehicular telemetry system. Data redundancy reduction may be achieved with a variety of techniques varying from simple first-order systems which merely compare the next measurement to the last and transmit the data word only if a significant change has taken place, to higher order systems which may compare actual rates of change of data against expected parameters and transmit the data only if it is unusual (i.e. not expected). In any data redundancy reduction technique, compromises must be made by the system design engineer in establishing the functional parameters in balancing desired and efficient bandwidth savings versus possible loss of data under conditions where a multiplicity of data channels simultaneously change at their maximum rates. Here statistical theory of the type now rapidly being developed for telephonic