# WILD GOOSE
# Loran-C
# ASSOCIATION

INTERNATIONAL LORAN ASSOCIATION

## Symposium

## 1972
## Boston, MA

3 already have available 550 pages!

## ED DURBIN
## TELEDYNE SYSTEMS

300324

Mr. Durbin headed up the technical paper committee. At the symposium Mr. Durbin introduced each of the speakers. The technical papers were presented by some of the leaders in Loran Technology, and covered the spectrum of Loran from past to present to future. Summaries of each paper are presented here along with the speaker's name and company. Anyone interested in obtaining copies of the papers, is requested to write to the individual concerned.

/ 090 * 1 Ref 586

## COMMANDER WILLIAM F. ROLAND
## U.S.C.G.

Commander Roland gave a presentation entitled "Loran Station Presque Isle - Prototype for the Future".

The Coast Guard is building a new Loran Transmitting Station at Presque Isle, Maine. This station will be used to test the prototype equipment for a new concept in Loran-C transmitting station operation. The design goal is to build an unmanned station capable of providing signals with an availability of no less than 99.7% including all planned and unplanned outages and with an accuracy better than any presently operational station. To do this we are building all new equipment with many new techniques for redundancy, fail-operative properties, maintenance-while-on-air, and remote sensing control, and maintenance.

* 2 OK REWRITTEN BY 587 in 1989 ...

## WALTER DEAN
## THE MAGNOVOX COMPANY

"How We Got To Where We Are"

Mr. W. Dean gave a historical view of Loran dating back to its conception during World War II.

The Loran system was developed at the Radiation Laboratory during World War II to meet the needs of the Navy in convoy operations, and to provide all-weather navigation for aircraft by day and night.

Today Loran is used world wide by both commercial and military users. The military application has advanced the state of the art to the point where Loran is used as the primary means of navigation in many areas. In addition the military use of Loran has opened the doors for Loran navigation by commercial air carriers. Commercial airlines are presently studying the feasibility of Loran navigation.

N040 * 3 Ref 588

## JOSEPH A. PARINI
## LEAR SIEGLER, INC. - INSTRUMENT DIVISION

Mr. Parini presented a paper on "A Remote Target Locating System" designated PAVENAIL.

PAVENAIL is the name of a program relative to a remote Targeting/Designating System in an OV-ID aircraft. A modified ARN-92 Loran Navigation System, Laser Ranger/Designator System, Night Observation System and an Attitude Heading Reference System make up the totally integrated system. This system has been used successfully in a tactical environment.



T

FIRST

WILD

TECHNICAL

NOVEMBER 30, 1

DESCRIPTIO

The following non-monetary
aims and purposes of the Wild

Medal of Merit:

To be awarded to a person o
of outstanding value to the dev
award shall normally only be gi
contribution is clearly recognized

Paper Award:

To be awarded to a member
best paper published on the gene

Service Award:
This award will be given to n
service to the Wild Goose Associa

MEMBERS

As of the last meeting c
Field on January 31, 1973 the to
three honorary members, Dan
Please use the enclosed applicati
it on to a worthy candidate.

No 40

# ...ONAL ...OOSE ...MPOSIUM

- BOSTON, MASS.

## ...F AWARDS

...ds are proposed to further the Association.

...ons for a particular contribution ...ent or fostering of Loran. This ...er the exceptional nature of the

... Wild Goose Association for the ...ject of LORAN.

...rs who distinguish themselves by

## ...P REPORT

...d of Directors at Hanscom ...embership was 221 including our ...ng, Gif Hefley and Harry Davis. ...ank to join the WGA now or pass

4

### CLAUDE J. PASQUIER
### LITCOM DIVISION OF LITTON SYSTEMS

589

Mr. Pasquier presented a technical description of the AN/PSN-6 Loran personnel navigator.

His presentation highlighted the specification requirements which make the Manpack receiver unique with regard to performance, size and weight.

In addition to detailed technical descriptions, block diagrams, and operational descriptions, the model of the PSN-6 and PRC-25 combination was demonstrated to the audience.

5

### ROBERT L. FRANK
### SPERRY GYROSCOPE DIV. - SPERRY RAND CORP.

have copy

Mr. R.L. Frank presented a paper which traced the evolution and development of some of the key techniques which have resulted in present day Loran systems.

Some of the early Loran systems used complex means of reading time differences. The first major development was direct dial reading of time differences. Cycle matching was developed for the Cyclan System. This system provided completely automatic pulse envelope tracking and cycle phase tracking.

Over the years, a number of Loran systems was developed until what we know today as Loran C-D systems. Today's systems provide not only navigation but tactical systems which include transportable Loran stations.

30735 RIVER CROSSING
BIRMINGHAM, MI 48010
(313) 645-9848

590

6

### JOHN HOPKINS
### TELEDYNE SYSTEMS COMPANY

have copy

Mr. J. Hopkins presented a paper covering the evolution of Loran-C through the developments of first generation receivers to the present day systems or second generation systems.

From first generation systems it was learned that the most serious limitations were size and cost, as well as performance improvement. The second generation systems will satisfy these requirements.

Through design innovations and higher density microelectronics, Loran-C receiver costs were slashed, many critical and expensive parts were eliminated, the overall parts count was reduced and performance was improved.

The spurt of new developments and burgeoning applications, signal the beginning of the rapid growth in Loran-C popularity.

591

7

### ROBERT A. REILLY
### ITT AVIONICS DIVISION

have copy

Mr. Reilly presented a report on Loran Processing Advances. Covered in his report were "Chronic Loran Problems" such as, Noise versus Dynamics and Cycle Ambiguity.

New techniques for combating these problems were discussed. Advanced processing techniques in the area of Signal Censoring - Peak Tracking - Adaptive Envelope were presented in detail.

Future efforts in Loran navigation, should be centered around better noise models, skywave statistics, propagation studies.

FIRST TECHNICAL SYMPOSIUM 1972

7 PAPERS

NOS 1-1, 1-3, 1-4 NOT PUBLISHED
AND MISSING.

#1

VAN ETTEN

# LORAN

# PROCESSING

# ADVANCES

VANETTEN
REF 591

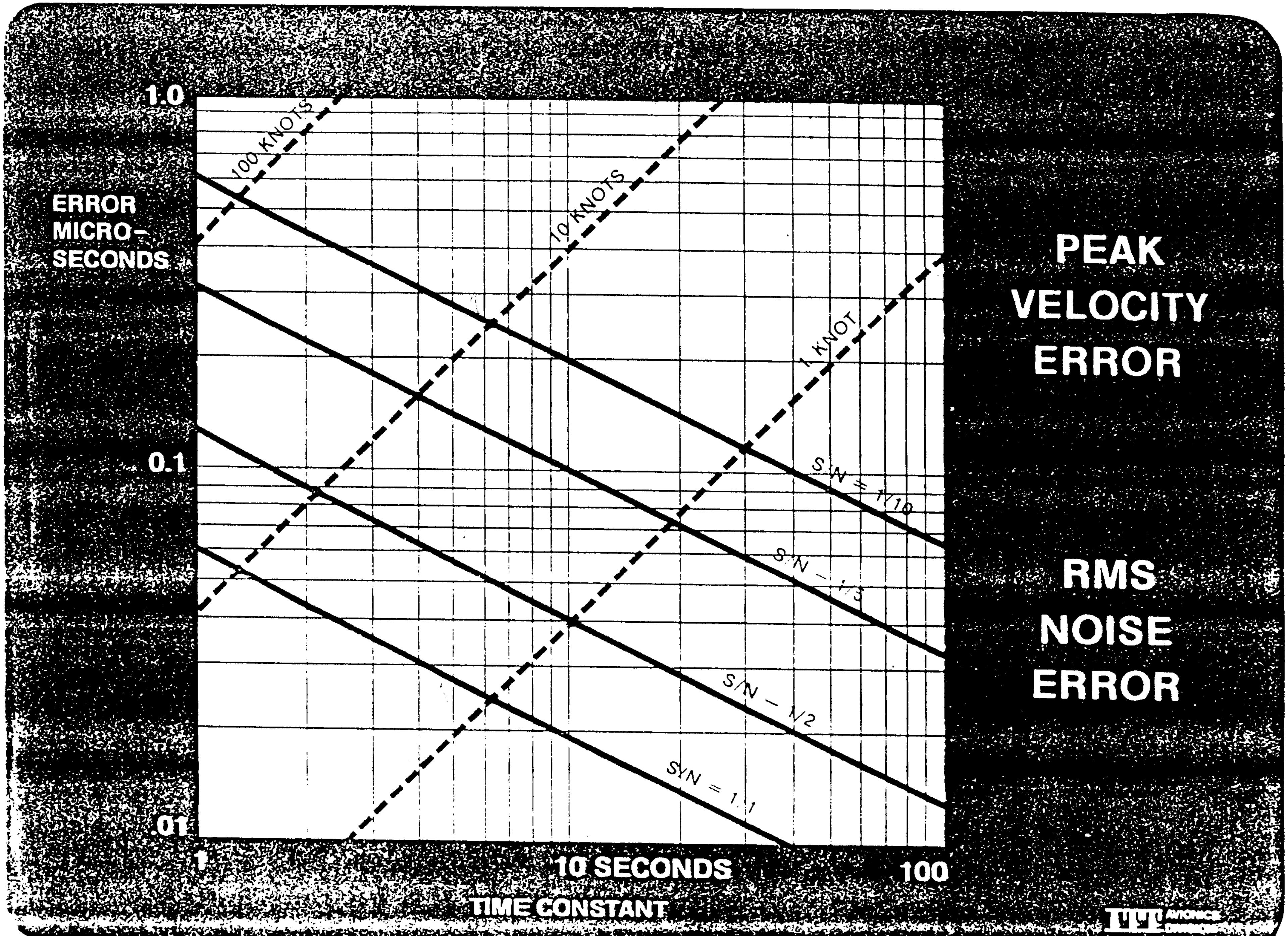
P122
PAPER1-7
JL890413

AVIONICS DIVISION ITT

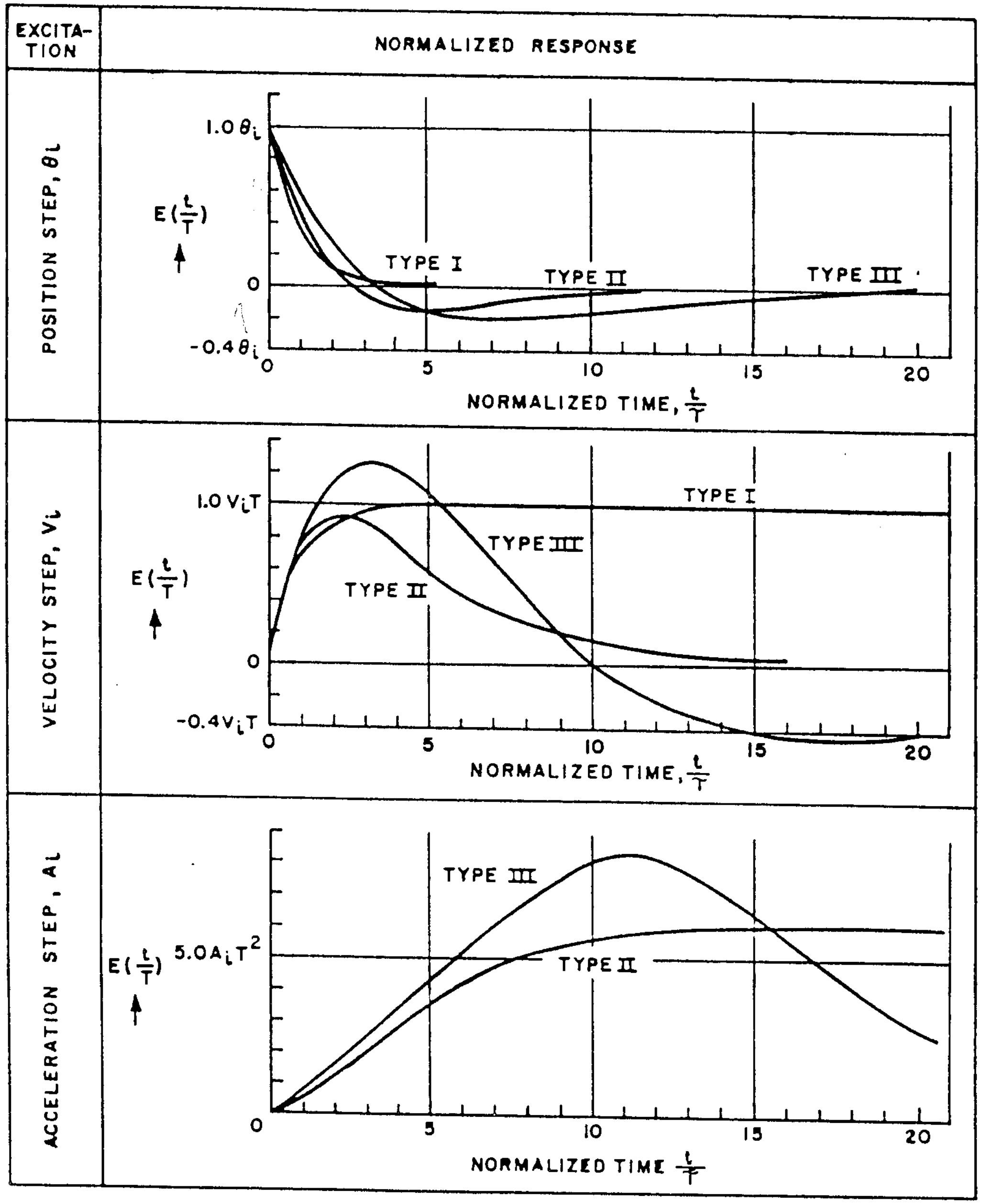
# CHRONIC LORAN PROBLEMS

NOISE VS. DYNAMICS

CYCLE AMBIGUITY


1.0
ERROR
MICRO-
SECONDS
0.1
.01
100 KNOTS
10 KNOTS
1 KNOT
S/N = 1/10
S/N — 1/3
S/N — 1/2
S/N = 1:1
1
10 SECONDS
100
TIME CONSTANT
PEAK
VELOCITY
ERROR
RMS
NOISE
ERROR
ITT AVIONICS

TYPICAL SERVO TRANSIENT RESPONSE



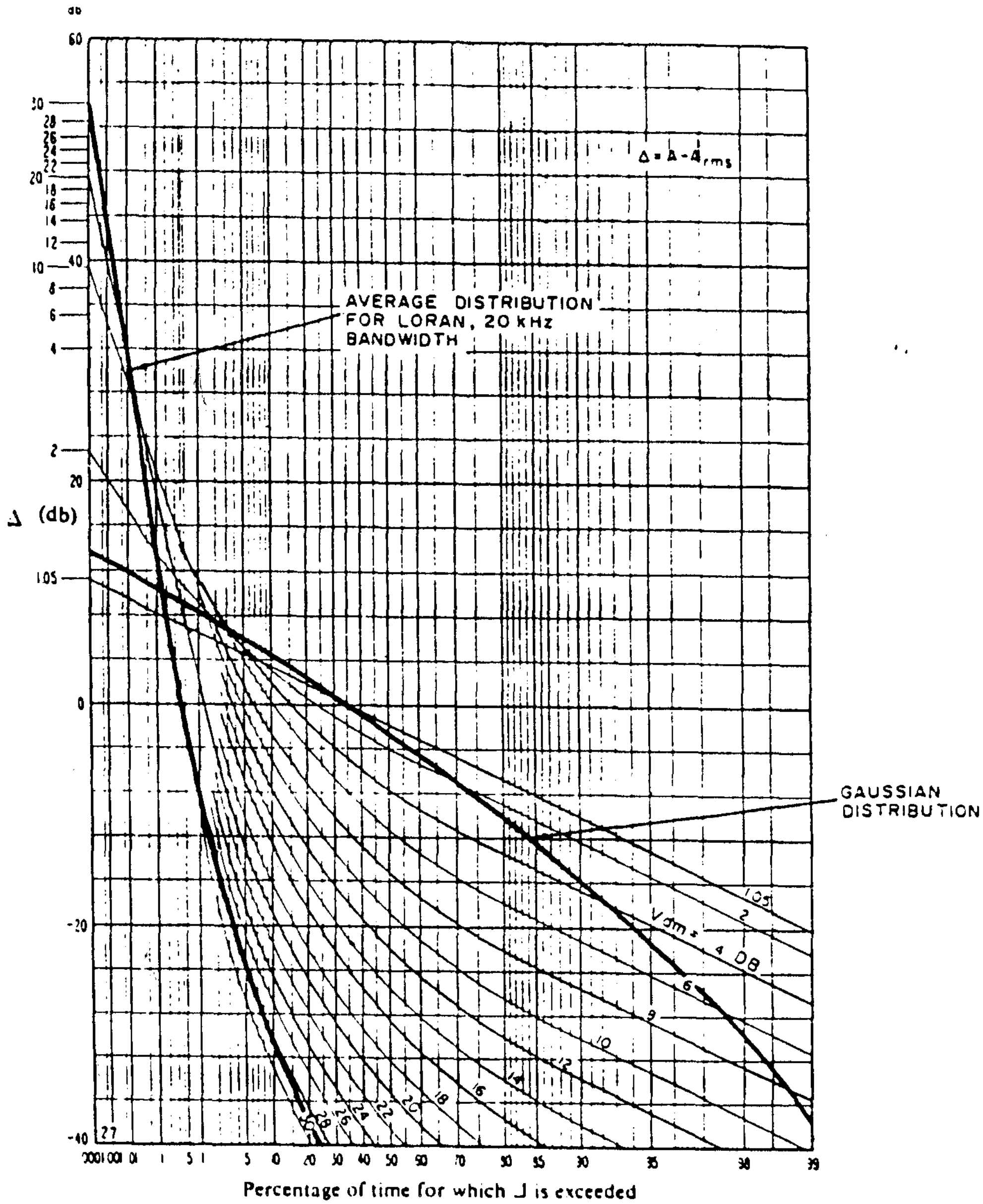
# ADVANCED PROCESSING TECHNIQUES

SIGNAL CENSORING

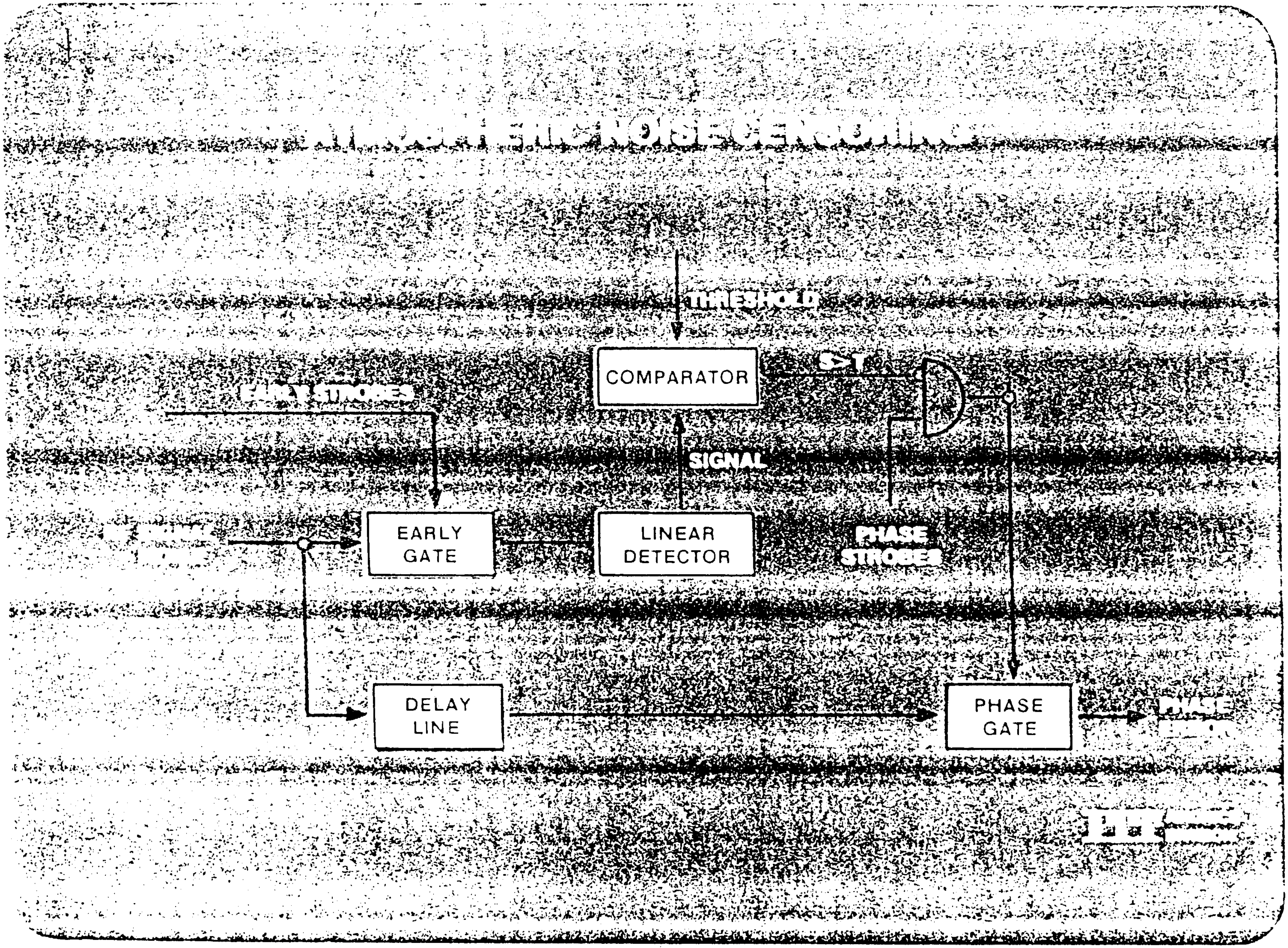
PEAK TRACKING

ADAPTIVE ENVELOPE

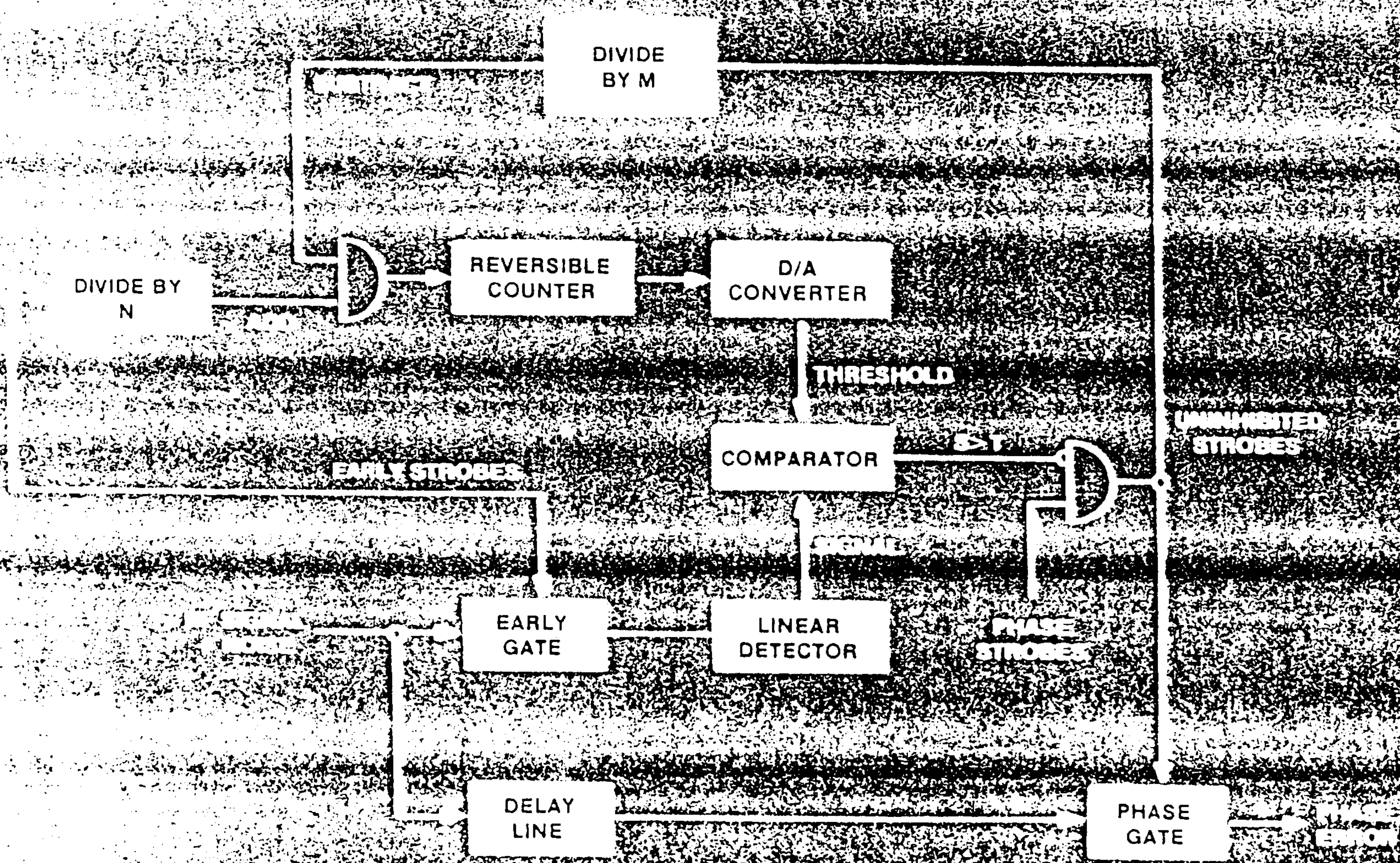
AMPLITUDE PROBABILITY DISTRIBUTION OF THE NOISE ENVELOPE

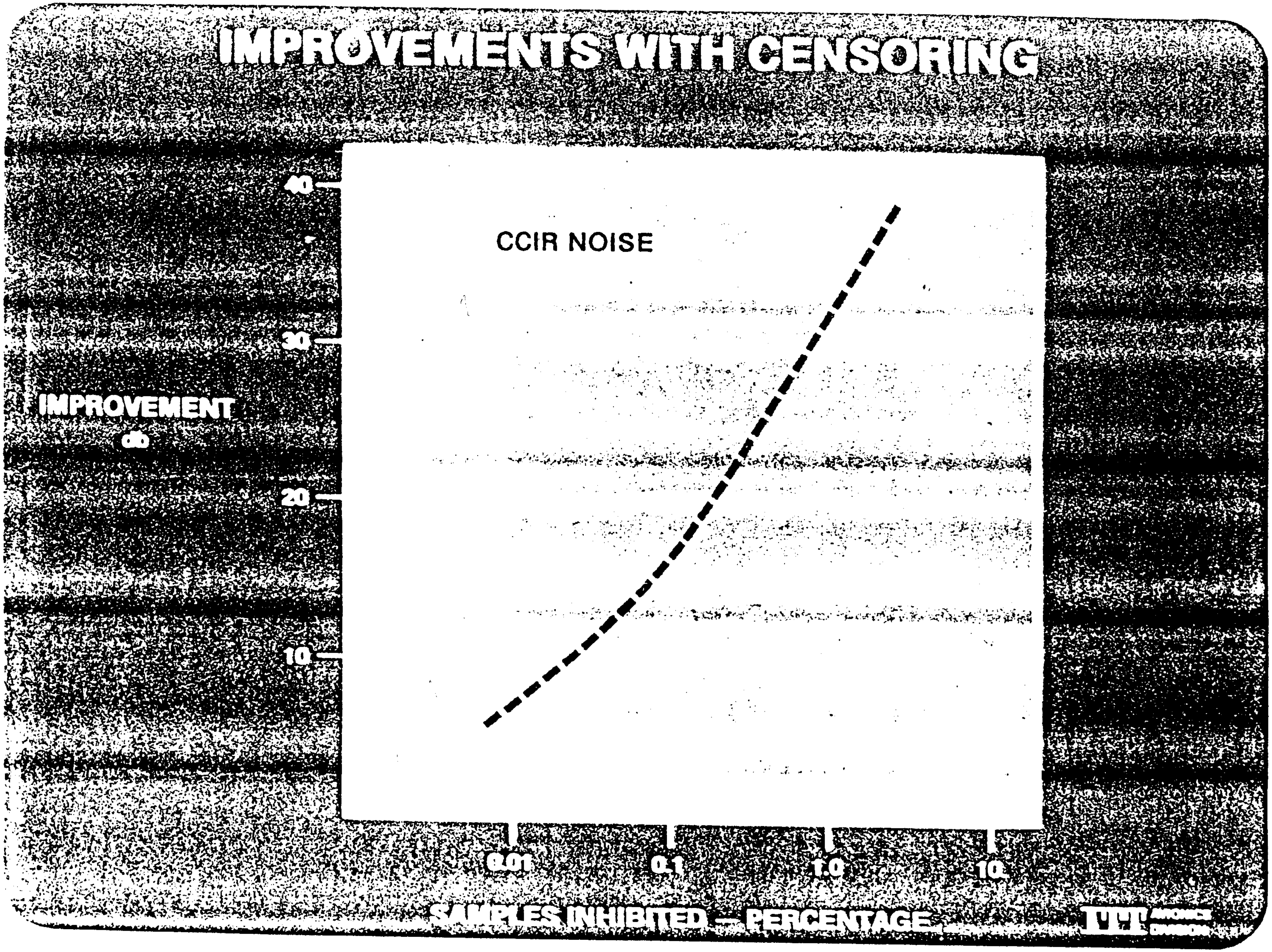



Adapted from CCIR 322 (13)


THRESHOLD
COMPARATOR
S>T
EARLY STROBES
SIGNAL
EARLY
GATE
LINEAR
DETECTOR
PHASE
STROBES
DELAY
LINE
PHASE
GATE

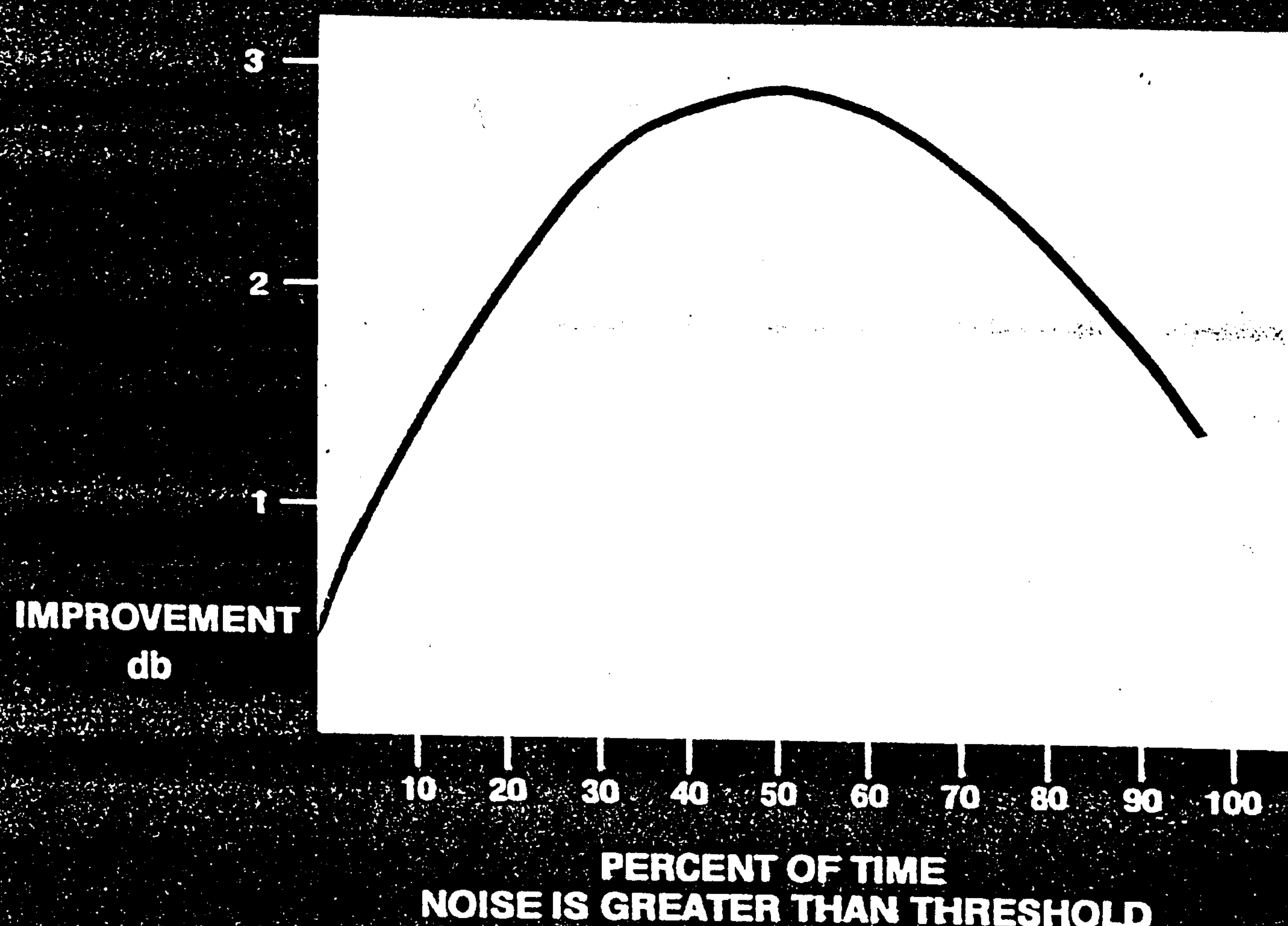
# TIC THRESHOLD ADJUSTMENT



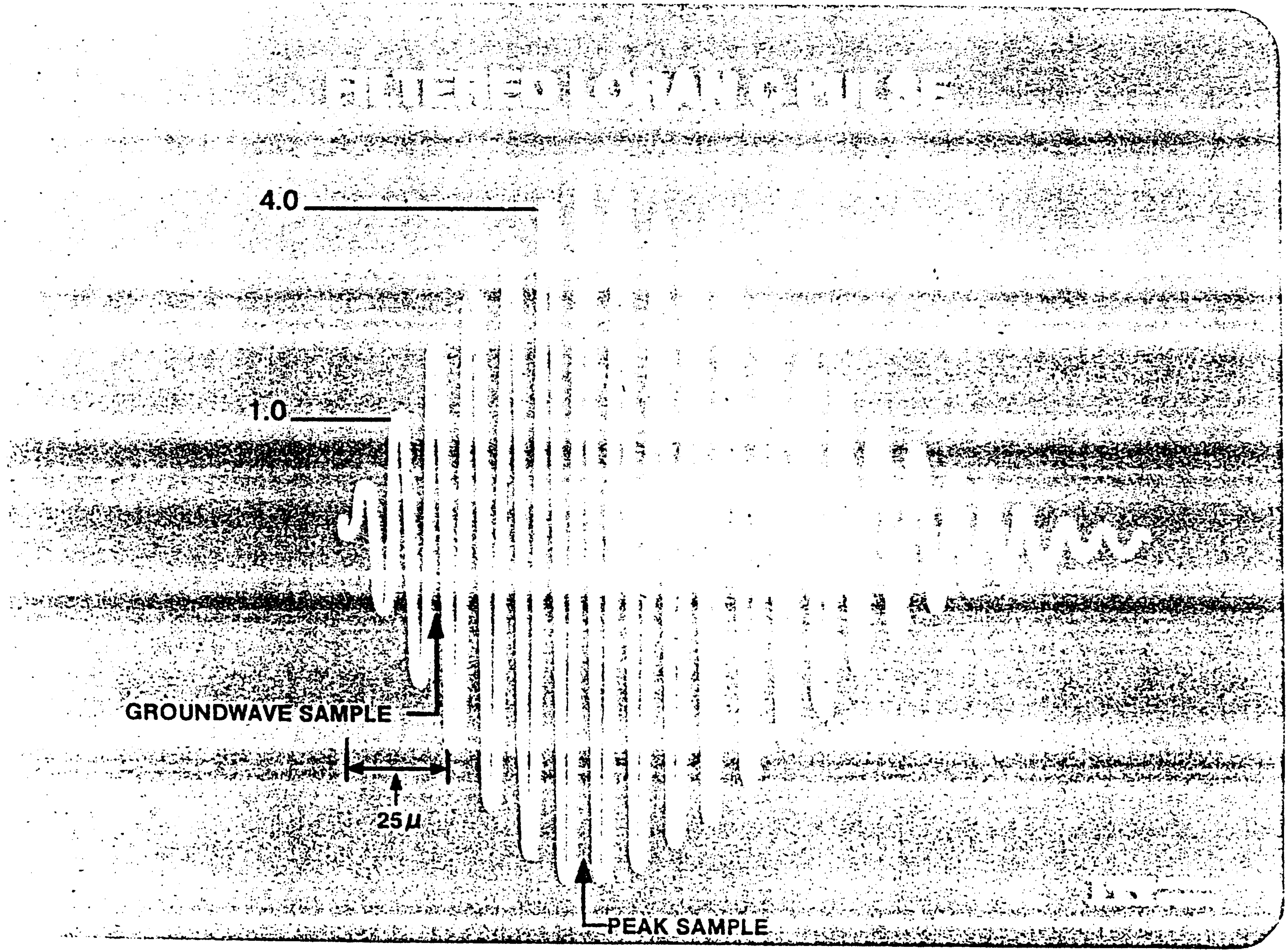


IMPROVEMENTS WITH CENSORING
CCIR NOISE
40
30
20
10
IMPROVEMENT
db
0.01
0.1
1.0
10.
SAMPLES INHIBITED — PERCENTAGE
ITT

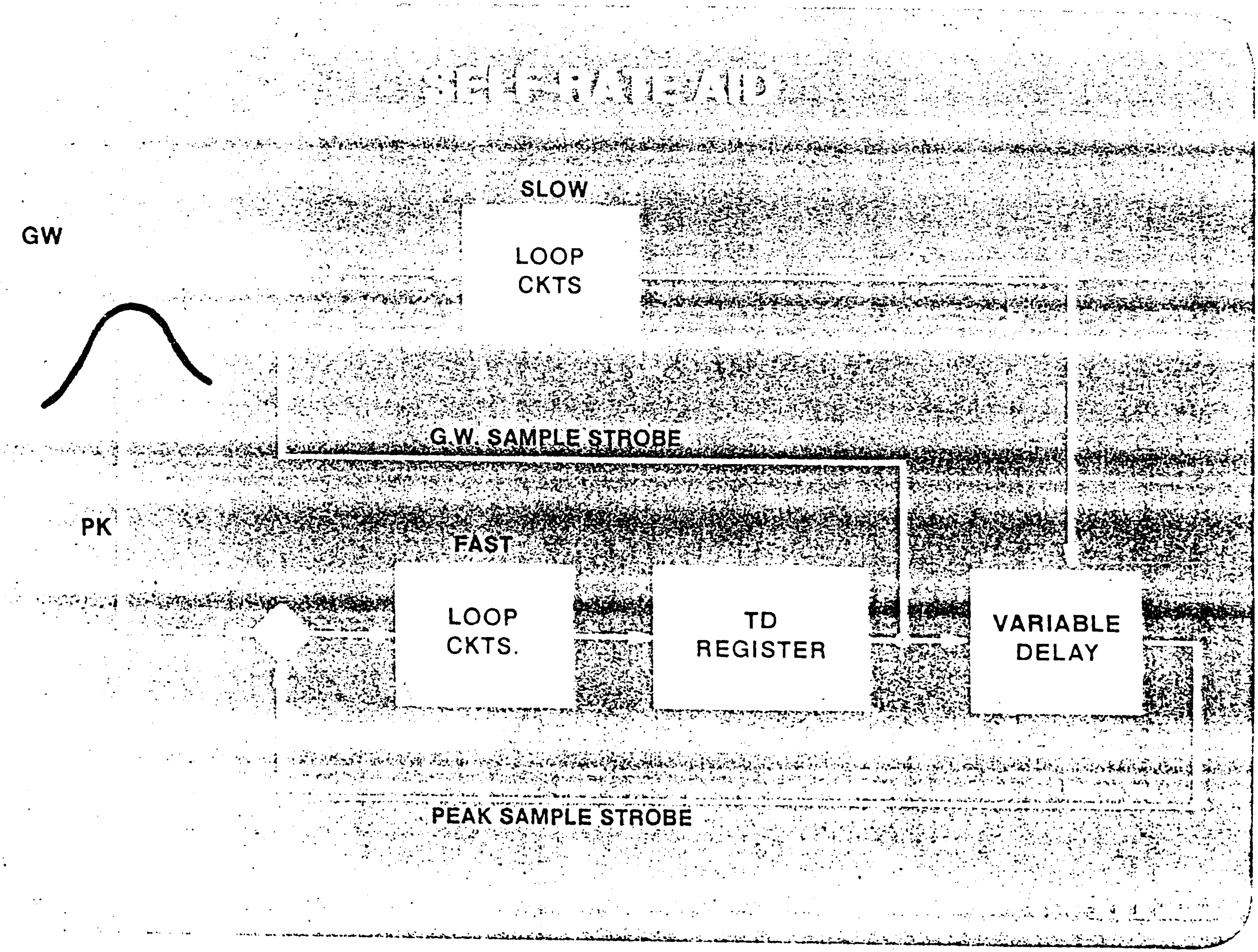
# GAUSSIAN NOISE IMPROVEMENT WITH CENSORING




ITT AVIONICS DIVISION



4.0
1.0
GROUNDWAVE SAMPLE
25 μ
PEAK SAMPLE


GW
PK
SLOW
LOOP CKTS
G.W. SAMPLE STROBE
FAST
LOOP CKTS.
TD REGISTER
VARIABLE DELAY
PEAK SAMPLE STROBE

# DERIVE VELOCITY FROM PEAK

SNR $>$ 4 TIMES BETTER

BW, 16 TIMES FASTER

ACCELERATION 256 TIMES SLOWER

CAN USE:

NB R.F.

HARD LIMITING

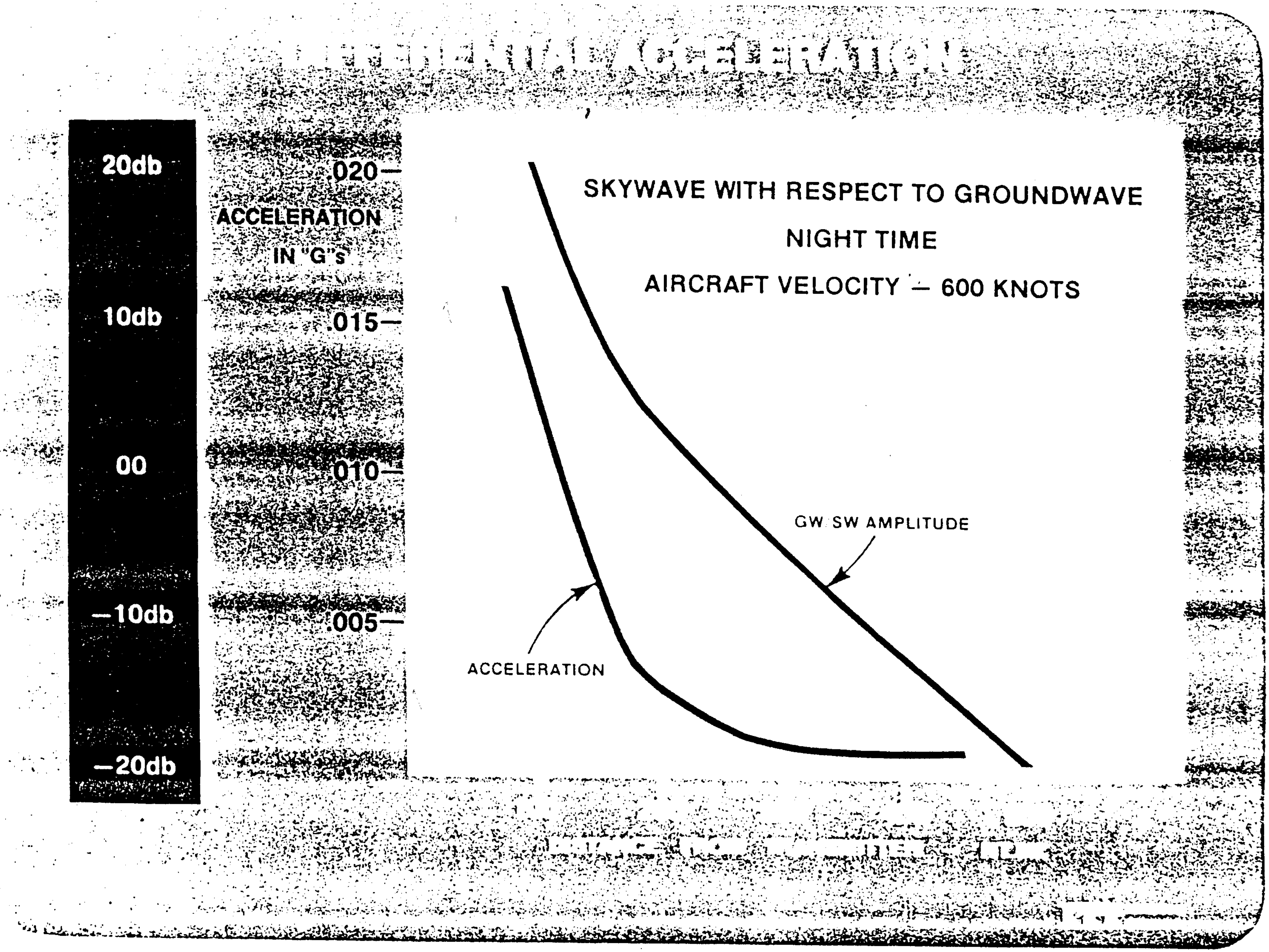
# ADVANTAGES

- NO RATE AID INTERFACE
- SIMPLER INSTALLATION
- LESS COMPUTER SOFT WARE
- INCREASES RELIABILITY
- OVERCOMES "WARP VELOCITY" ERRORS . . .

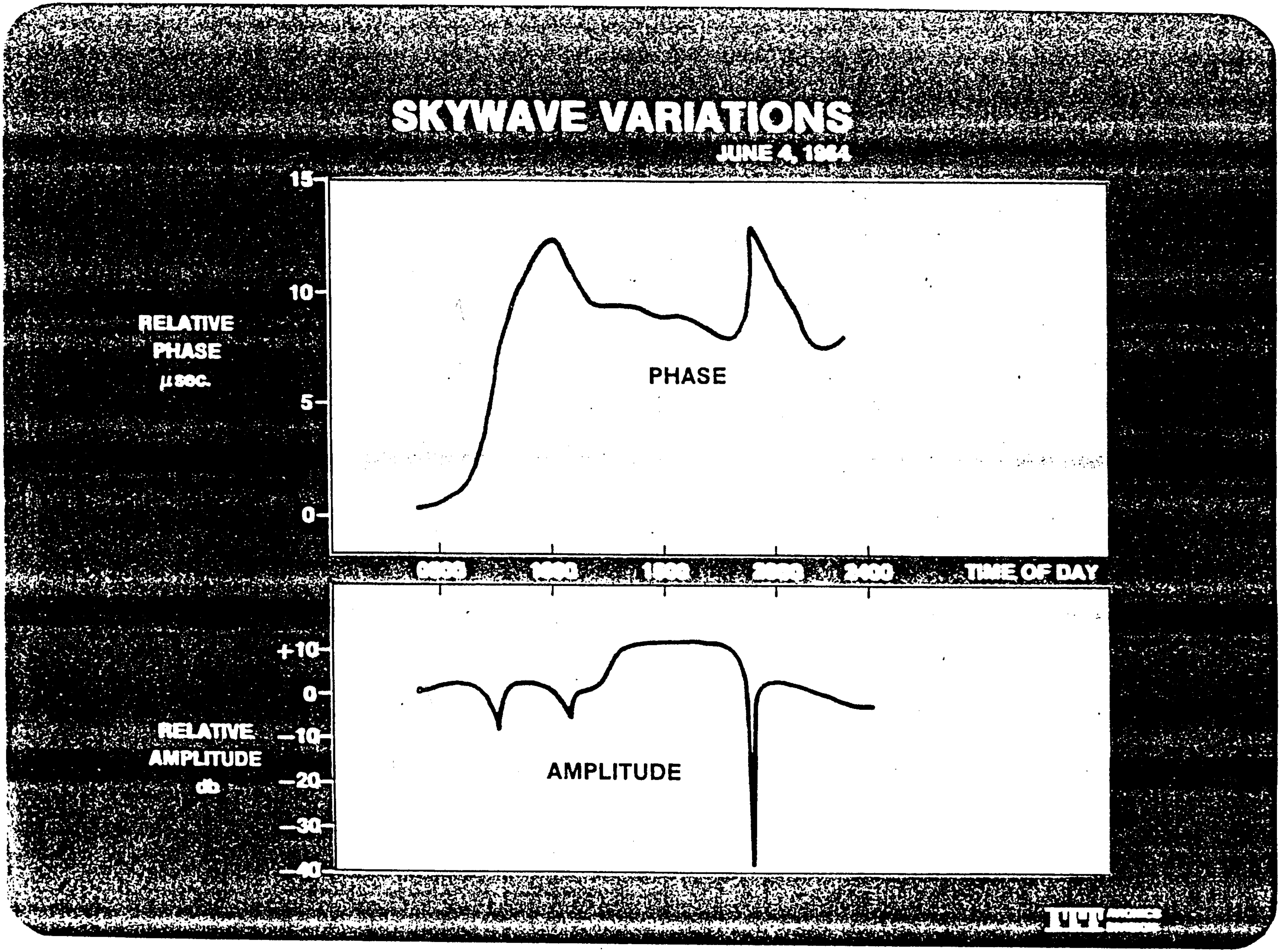
# PEAK TRACKING

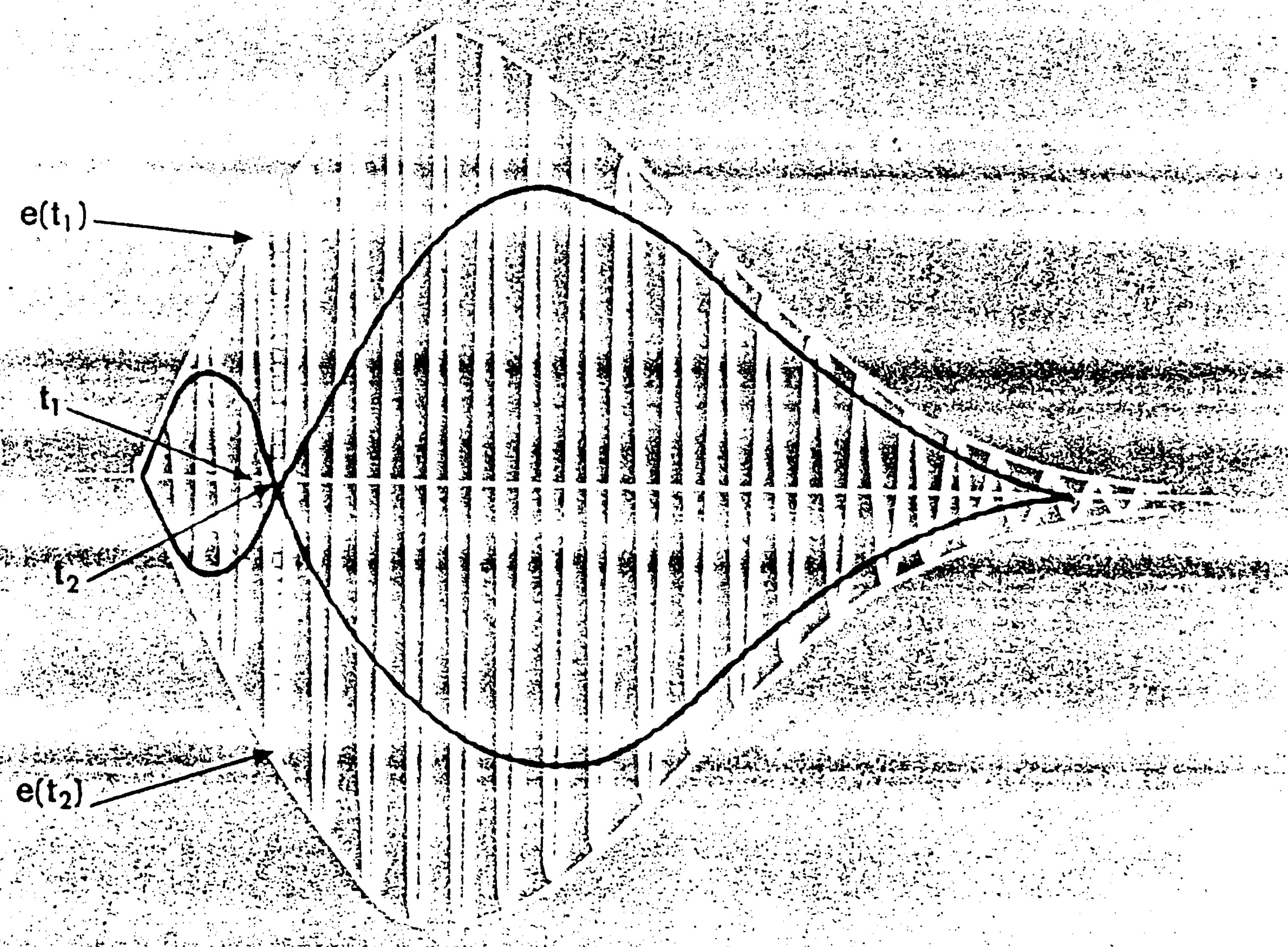
## PREDICTED TRANSIENT ERRORS IN F4-D DURING MANEUVERS IN SEA

| | PEAK ERRORS | | FULL ACCURACY RECOVERY TIME | |
|---|---|---|---|---|
| MANEUVER | PRESENT ARN-92 WITH INS RATE-AIDING | LORAN RECEIVER WITH SELF-CONTAINED VELOCITY AID/NO INS | PRESENT ARN-92 | LORAN RECEIVER WITH SELF-CONTAINED VELOCITY AID/NO INS |
| 2G | 600 FT. | 150 FT. | 30 SEC. | 3 SEC. |
| 4G | 1500 FT. | 300 FT. | 30 SEC. | 3 SEC. |

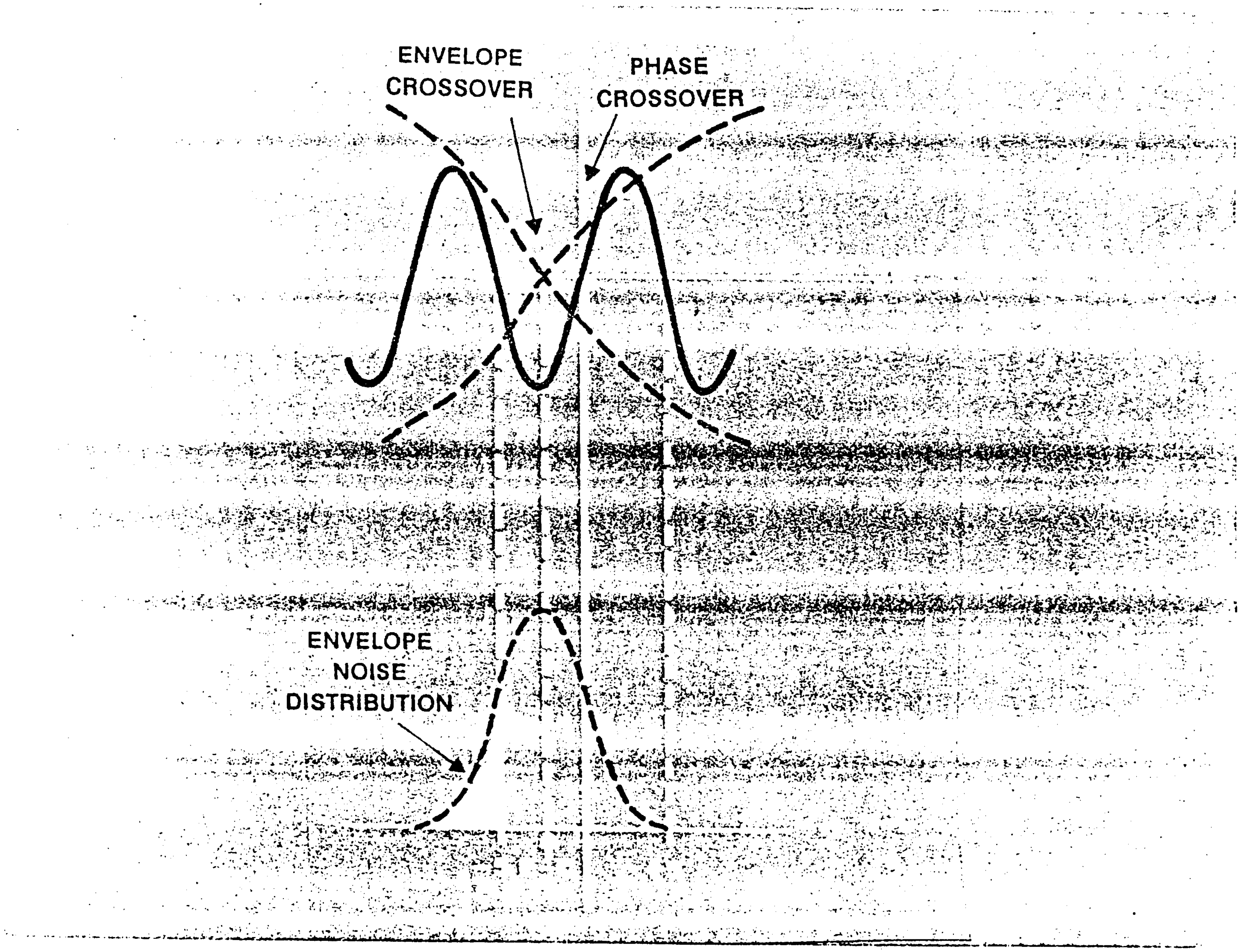


20db
10db
00
-10db
-20db
.020
.015
.010
.005
ACCELERATION IN "G"s
SKYWAVE WITH RESPECT TO GROUNDWAVE
NIGHT TIME
AIRCRAFT VELOCITY – 600 KNOTS
GW SW AMPLITUDE
ACCELERATION

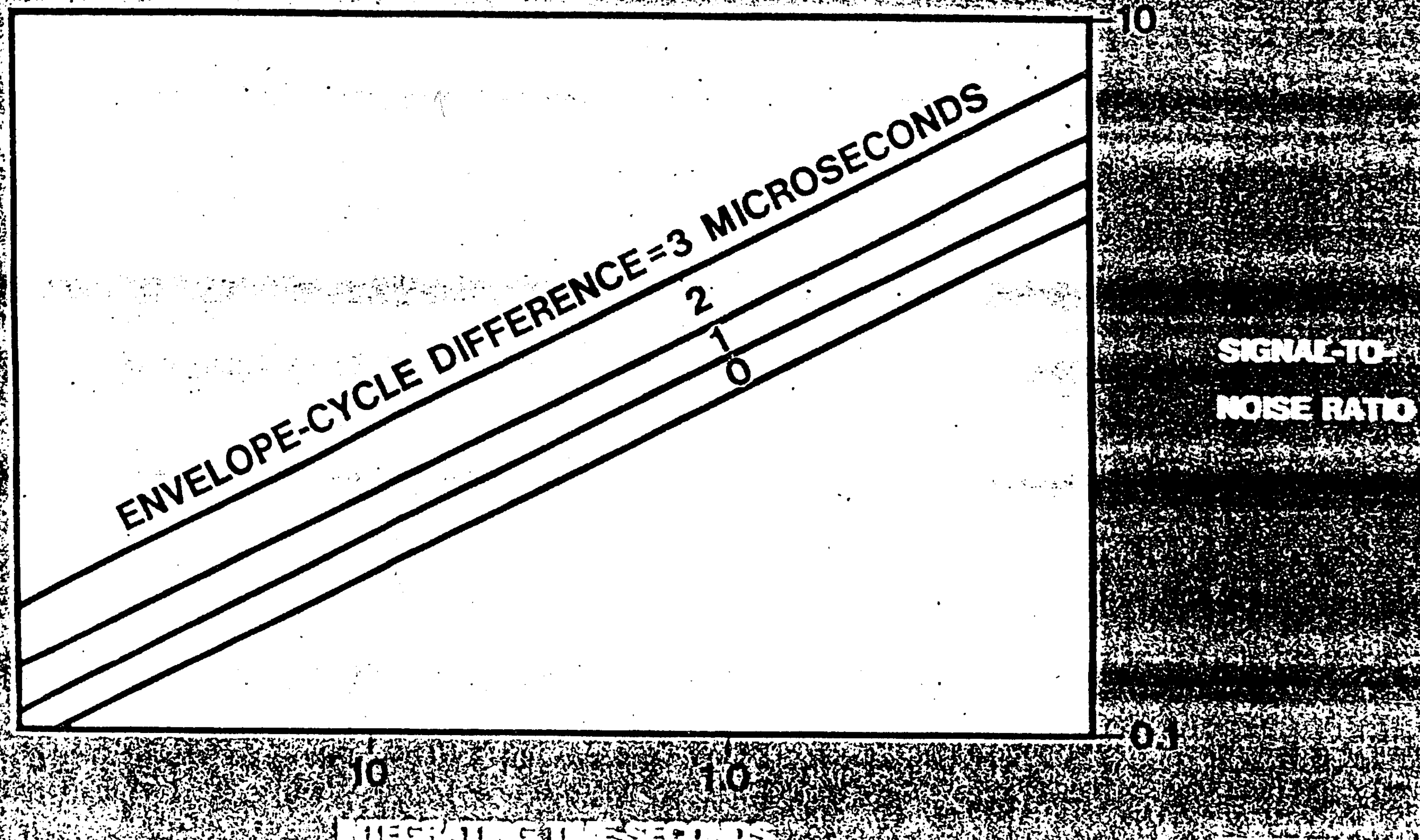

SKYWAVE VARIATIONS
RELATIVE PHASE µsec.
15
10
5
0
PHASE
2400
TIME OF DAY
+10
0
RELATIVE AMPLITUDE db
−10
−20
−30
−40
AMPLITUDE
ITT

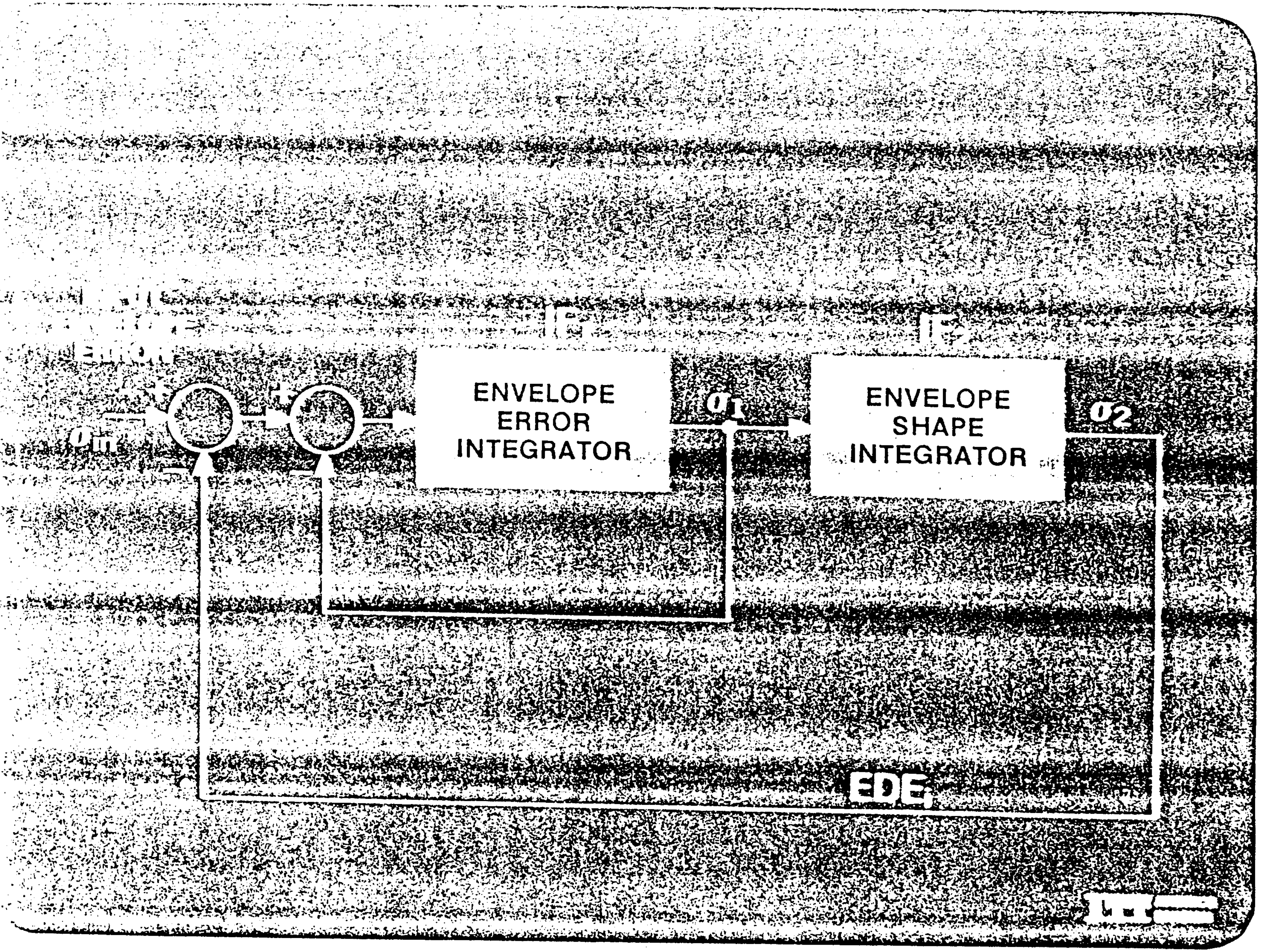


e($t_1$)
$t_1$
$t_2$
e($t_2$)


ENVELOPE
CROSSOVER
PHASE
CROSSOVER
ENVELOPE
NOISE
DISTRIBUTION

# INTEGRATION TIMES CYCLE IDENTIFICATION




ENVELOPE
ERROR
INTEGRATOR
ENVELOPE
SHAPE
INTEGRATOR
EDE

# FUTURE EFFORTS

- BETTER NOISE MODELS
- SKYWAVE STATISTICS
- PROPAGATION STUDIES

#2

WALT DEAN

The following is a slightly edited transcription of the tape recording of

How We Got to Where We Are
by
Walter N. Dean

presented at the First Annual Wild Goose Technical Symposium.

To start out with, I made up a Loran family tree (figure 1). The loran business really started in the Radiation Lab way back at the beginning of World War II. It started out as a high frequency system - I'm not sure everybody realizes that, but it did, and it was after some soul searching and experimentation they finally took over some of the hams' 160 meter phone band and set up some stations working at about 2 megacycles. They discovered that system worked pretty well and decided to continue there. One of the interesting things about loran at that frequency was that, particularly at nighttime, the skywaves could be separated from the groundwaves and the system could operate either on the groundwave or the skywave.

Now, back to this family tree, there are several outgrowths. SS loran, skywave synchronized loran and the other three variations of standard loran, then low frequency loran and all the other things that came out of it. That is going to be the subject of this paper. To go back a bit, skywave synchronized loran really got its big push during the war when we were trying to make night bombing raids on Germany. Two chains were set up, shown in figure 2, one pair going from Scotland to Algiers, the other pair being in northern Africa. They provided two lines of position which intersect almost at right angles over Germany. It is my understanding that the Germans never actually realized what was going on, that is, that these signals were being used by the bombers in making their bombing raids over Germany and they were actually flying loran lines of position on those raids. SS loran expanded later into the Pacific.

The present coverage of Loran-A, as seen in figure 3, was mostly put in during the war, with the result that the Loran-A coverage in the Northern Hemisphere is quite extensive. You probably remember from the block diagram the box called "LODAR". That was a little project that Win Palmer worked on. LODAR stands for Loran Direction Finding. The ability of loran to separate the groundwaves from the skywaves made the biggest problem involved in d-f suddenly disappear. It was possible to make d-f measurements very accurately either on a groundwave or a skywave, and so this suddenly became a very interesting subject. Unfortunately, it turned out that by the time you got all the instrumentation required to do this job, you might just a well make time difference measurements rather than d-f measurements. However, this is something to think about in the application of Kalman filtering to the overall loran problem. The direction information to stations is available to a high degree of accuracy by separating the groundwave from the skywave.

Standard loran did its job during the war , but it had problems, illustrated by figure 4. This shows that over seawater the 2 megacycle groundwave drops off quite rapidly. At 180 KC propagation is considerably better, and 100 KC it is better still. This is seen even more in figure 5 which shows that over land 2 megacycles disappears amost completely within 100 miles or so, whereas the low frequencies are propagated to considerable distances. The Air Force had an interest in overland propagation, and so the Signal Corps and the Air Force set up a chain of loran stations operating at 180 KC which was finally operaitonal in 1944. They had a station in Brewster, Mass, one in Ft. Caswell, N.C. and one in Key Largo, Fla., a fine job of site selection. They ran a series of tests and took a lot of data and then wrote a very good report on it, ORS-P-22 and ORS-P-23, which are now in very short supply.

This 180 KC loran had one distinct disadvantage - they were able to make envelope measurements and they wre able to match cycles, but they were unable to make the envelope match to the accuracy to reliably select the proper cycle.

The L.F. loran chain was then used in Air Force operations that took place shortly after that: one was Operation Musk Ox in Canada. The Air Force took the LF loran stations out of the East Coast and shipped them to Canada. Barrage balloons were used to support antennas and they set them up, one in Gimley, one in Hamlin and one in Dawson Creek. This chain was used for navigation of the aircraft up there. They were dropping petroleum ot installations in the the northern Canada area and they were very successful in using loran for navigation. It worked so well they decided to use it during Operation Beetle in the northern part of Alaska. Stations were set up, one at Cambridge Bay, Yukon, one at Kittigazoot and at Skull Cliff Alaska. They moved the transmitting stations there and built 625 foot towers for the antennas. Unfortunately, the poor conductivity of the permafrost made it impossible to synchronize the stations - they coundn't receive the Master at the Slaves, so the whole thing turned out to be pretty much of a fiasco.

About that time, however, Win Palmer back at Sperry was thinking about how to resolve the cycle ambiguity of the system. He came up with the idea of using two frequencies, 180 and 200 KC, and he called the system CYCLAN. He sold the idea to the Air Force and we built up a couple of transmiters and a monitor receiver. We set up the transmitters at the Makcay radio stations on the West Coast at the end of 1949. Mackay had two stations, one at Palo Alto, Californie and the other at Hillsboro, near Portland, Oregon, each with a 625 foot tower. Figure 6 shows the one at Palo Alto.

The only problem was that the towers were grounded, and so a special feed for the antennas was needed. The coupler was mounted at the top of the tower. The antenna cable ran all the way up the tower and fed into this coupler which drove the top loading elements and induced currents back into the grounded antenna. We operated there with 10KW transmitters. We also had, of course, the problem of restricting our sidebands at 180 and 200 KC, so we had a bandpass filter built to restrict the sideband radiation.

The monitor receiver was mounted in a K31 van, a real beauty. It had 10 speeds forward and 4 reverse. A sign on the dash identified a maximum speed of 45 miles per hour and it really meant it. On a downhill run I was once able to reach 48 mph, and the van tried to shake itself apart. We had the monitor reciever in the van. Receivers in those days were a bit different than they are now. Figure 7 shows a small part of the receiver which operated at 180 and 200 KC. Actually, by the time this picture was taken the CYCLAN program had gone through another cycle. We had had some problems with the 10 KW transmitters because the stations were 550 miles apart, and, as we expected, we could synchronize in the daytime but not at night when the noise was too high. In addition to that, one day we turned on the receiver and the scope was solid with interference, bigger than any of our signals. We noticed that it was sending Morse code, the letters MOR. It turns out that MOR was what they called a new medium frequency omni-range. Actually, it wasn't medium frequency at all, it was operating at 190 KC, with 10 KW output. The CAA had installed it in Half Moon Bay, just over the hill from us in Palo Alto, and had just turned it on, to experiment with the MOR.

That and several other problems induced us to change the frequency from 200 KC to 160 KC. The Air Force contracted with Sierrra Electronics to build 100 KW amplifiers for the transmitters. We went back to California and the receiver in the K31 van. We finally got measurements on the baseline extension near Palo Alto and then moved to Death Valley. Measurements there demonstrated the poor conductivity of the mountains and the valley. Most of the operational data was taken at Reno. We found that we were able to measure time differences to a standard deviation of .06 microseconds, about a 34 foot error in line of position at Reno.

All the evidence indicated that if we went down to 100 KC we would be able to do cycle matching on a single frequency and we would have a system that would work on one frequency. Unfortunately, about that time the Air Force decided that a system named WHYN, which stood for Wobbulated Hyperbolic Navigation had more promise. It turned out to be nothing but promise. The next year the Air Force decided they did need a loran type system to be an all-weather tactical bombing system.

The new system was named CYTAC, because CYCLAN was obviously obsolete. For the first time multiple pulsing and phase coding were used. Because we knew it would never have to be compatible with loran, a repetition interval of 51.2 milliseconds was selected. We had three transmitters - one at Forestport, New York, which you have all heard of, one at Carolina Beach, N.C., and one at Carabelle, Florida. We got the one at Forestport started first. There we had the 1100 foot tower and produced some very interesting propagation results. We had what we called a ground monitor receiver located in a trailer that was hauled around the country. We started out working our way west from Forestport. The people at Stanford Research Institute had developed a nice little modulator for us, that gave us a pulse only 5 cycles long, with a 3 cycle rise time. It was very nice, and it made for excellent propagation measurements. Unfortunately, some of our Canadian neighbors objected, so we had to go to a longer and less violently rising pulse. When the receiver trailer took off to the west, the Bureau of Standards was with us with their own instrumented trailer. We made the first good propagation measurements of skywaves to determine tha ability to propagate beyond what was called the geometrical-optical line of sight.

NBS really couldn't settle for their little trailer, so they decided they needed something better, and by the time the program was half over they had one with which they were able to do some very interesting things. For example, we had the airborne recieiver in a C47 and we were using it to fly over a ground monitor. The NBS people decided they would make a camera obscura inside the trailer and with that they could see the plane fly overhead and they could tell exactly what its flight path was. This was a lot quicker than the vertical camera photographs we had previously used. In order to fly a line of position we had some little problems with logistics. Smudge pots were used as markers to tell the C47 which way to fly.

The airborne receiver was supposed to be mounted in a pod. Figure 8 is a drawing of the way it was going to be. It was to go under the wing of a fighter, an F84, I think it was. It could almost have gotten in there except for a few of the servo components which we never did get miniaturized.

We also investigated a portable antenna. Figure 9 shows the balloon we used to lift a single wire antenna. We flew this up at Forestport and found that it worked very well.

About that time the B29 with the airborne receiver was finally getting into operation and making some good measurements of actual navigation of the aircraft with the computer. Unfortunately, at that time the Air Force decided that the CYTAC system had too many problems and that inertial systems could satisfy all the requirements, which meant a ground based tactical bombing system wasn't reqlly required, and so the CYTAC program was shut down

A couple of things mitigated that a little bit. You may have noticed on the block diagram the little word "NAROL", which is loran spelled backwards. Just about the end of the CYTAC program, there was a nuclear test series in Nevada called Operation Teapot. People at AFCRL had decided that they ought to be able to locate the explosions via the electromagnetic pulse. This, of course, was classified for a long time, but it no longer is.

It just happened that when the CYTAC program was over the Pacific nuclear tests Operation Redwingcame along, and so we took three ground monitor receivers and one transmitter out into the Hawaiian Islands area. We set up the transmitter at Haiku, on Oahu. This was the only time that the loran transmitter was used with a valley span antenna. It actually used the antenna that had previously been used for RADUX, a name which you may find familiar, and the RADUX equipment was still in the building we occupied during Operation Redwing. One of the monitors was at Midway Island, one on Maui, and the third down on the island of Palmyra, which has an air strip that had been used extensively during World War II. As a matter of fact, there were quite a few facilities, including a tennis court. The island was actually owned by the Fullard-Leo family of Honolulu, and Otto Hornung, the caretaker, spent all his time in a tiny house on Palmyra. All the buildings were pretty well run down, but we were able to operate a monitor there and the system did what it was supposed to do. A picture of the ground monitor receiver (GMR) out of the trailer to move to Palmyra is shown in figure 10 . Everything except the rack at the extreme left is the GMR, essentially a second generation of the loran receiver. That form of construction made it very handy for troubleshooting, which was occasionally necessary.

About the time we got back from Operation Redwing in mid-1956, the Navy had decided that they needed an accurate positioning system for their survey ships. The Coast Guard then came to Sperry to buy a modification of the CYTAC system. Agin, the name was changed to protect the innocent, and Loran-A, -B and -C were born. Of course, the first thing we had to do was to move the transmitters, as the configuration for CYTAC wasn't ideal for covering the ocean areas. The Forestport station was moved to Marthas Vineyard, and the Carabelle station moved to Jupiter, Florida.

In '58 we had just about finished what was a prototype of a transistorized airborne receiver. Actually, it was the first, and I think only, receiver with random size modules, for which Bob Frank can take full credit, or blame, whichever is appropriate. Although designed as an airborne receiver, it was eventually bought by the Navy and named the AN/SPN-28.

The first model we took in a Coast Guard R5D for flight tests. We wanted to see whether skywaves could really be received at long distances, so we headed south. We went to San Juan, then to Trinidad, to Belem, and finally wound up at Natal. Figure 11 shows signals at night in Natal, with the top trace the signal from the Master, the middle one Jupiter and the lower one Marthas Vineyard. We were actually locked on the first hop skywave and you can see the second dand third hop skywave there. We were able to use those signals to get position information which was good to a mile or so over 3,000 miles away.

1958 was also the antenna at Carolina Beach came down. One of those hurricane ladies came along and neatly chopped the self-supported antenna down. Since then the Coast Guard has been experimenting with antennas at Carolina Beach, and now has an inverted V.

The next Loran-C chain instlalled was the Mediterranean chain. The FPN-39 transmitters were installed at varous places in the Mediterranean. The chains proliferated over the next few years, so that the Loran-C coverage at the present time looks something like figure 12.

You might have noticed on the family tree the word "NUDES". This was actually the AN/GSQ-44 and NUDES stood for Nuclear Detonation Evaluation System. Actually the installation was the reason for the Sylt station going to Germany. The GSQ-44 equipment was installed in Air Force trailers, and they had three of them situated in Germany for a while until the U. S. Air Force stationed in Europe got tired of maintaining them and sent them home.

One of the other things on the block diagram is timing, and of course there have been a lot of things done recently in loran timing. Figure 13 is a copy of part of the report we get weekly from the Naval Observatory showing the time phase of the various chains as a function of time. You can see that the variation is generally less than a tenth of a microsecond per day.

Loran-B, shown in the block diagram, was an idea that never got off the ground. LORET is another loran variation that has been successful except that the military hasn't bought it for applications such as search and rescue.

The last part of the diagram is loran communkcations. The coast Guard of course has used loran pulse time modulation on loran pulses for their interstation communication on the Southeast Asia chain. The Navy started a program called Yankee Clipper, finally named Clarinet Pilgrim, which takes a 50 baud data stream and modulates it on 6 of the 8 pulses in the Loran-C group. That system has been installed in the Southwest Pacific. One interesting feature of the Southwest Pacific is the multi-hop skywave. Figure 14, taken at Iwo Jima one night shows the skywaves for at least 2000 microseconds.

The one thing that I have been impressed with in this operation is that development has been interrupted several times, mostly because the customer decided that other better promoted systems were preferable for reasons that were generally not technically sound. This is reflected even now in pressure from other navigation systems, some of them better promoted than loran. It is again tending to push the loran system out of certain applications. I think this is something that we should remember and be cognizant of, and recognize that the selling of loran is a very important function for all of us.

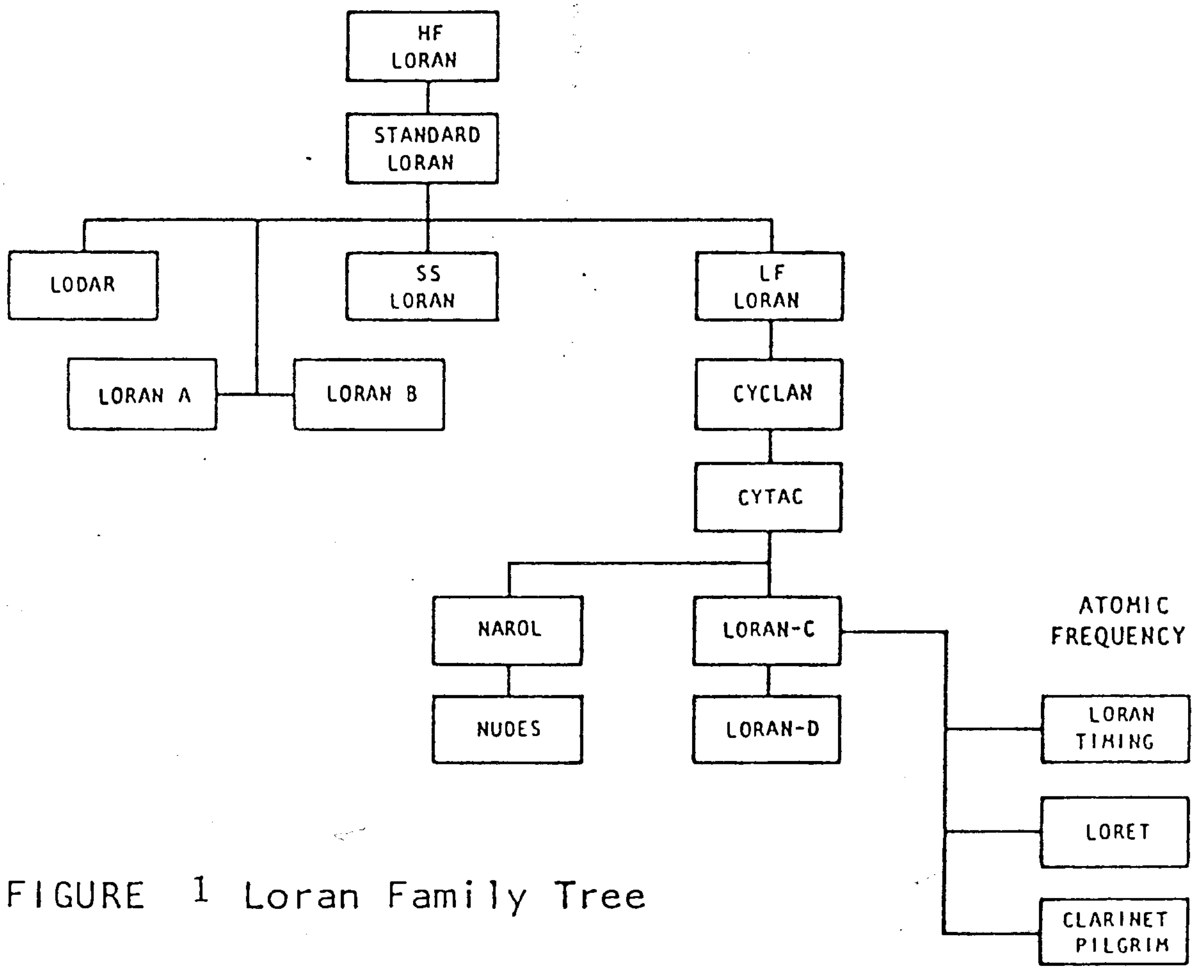



FIGURE 1 Loran Family Tree

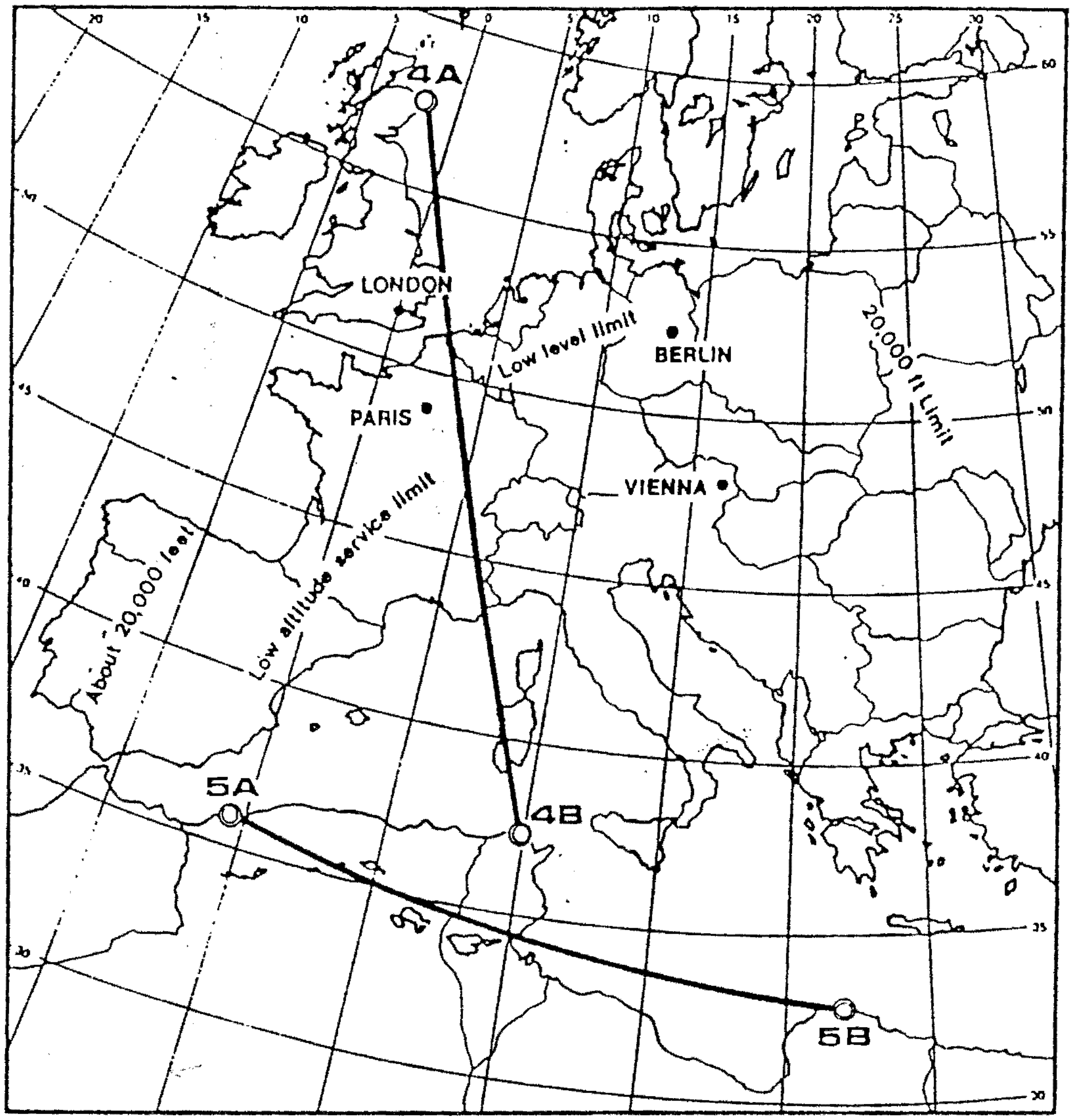
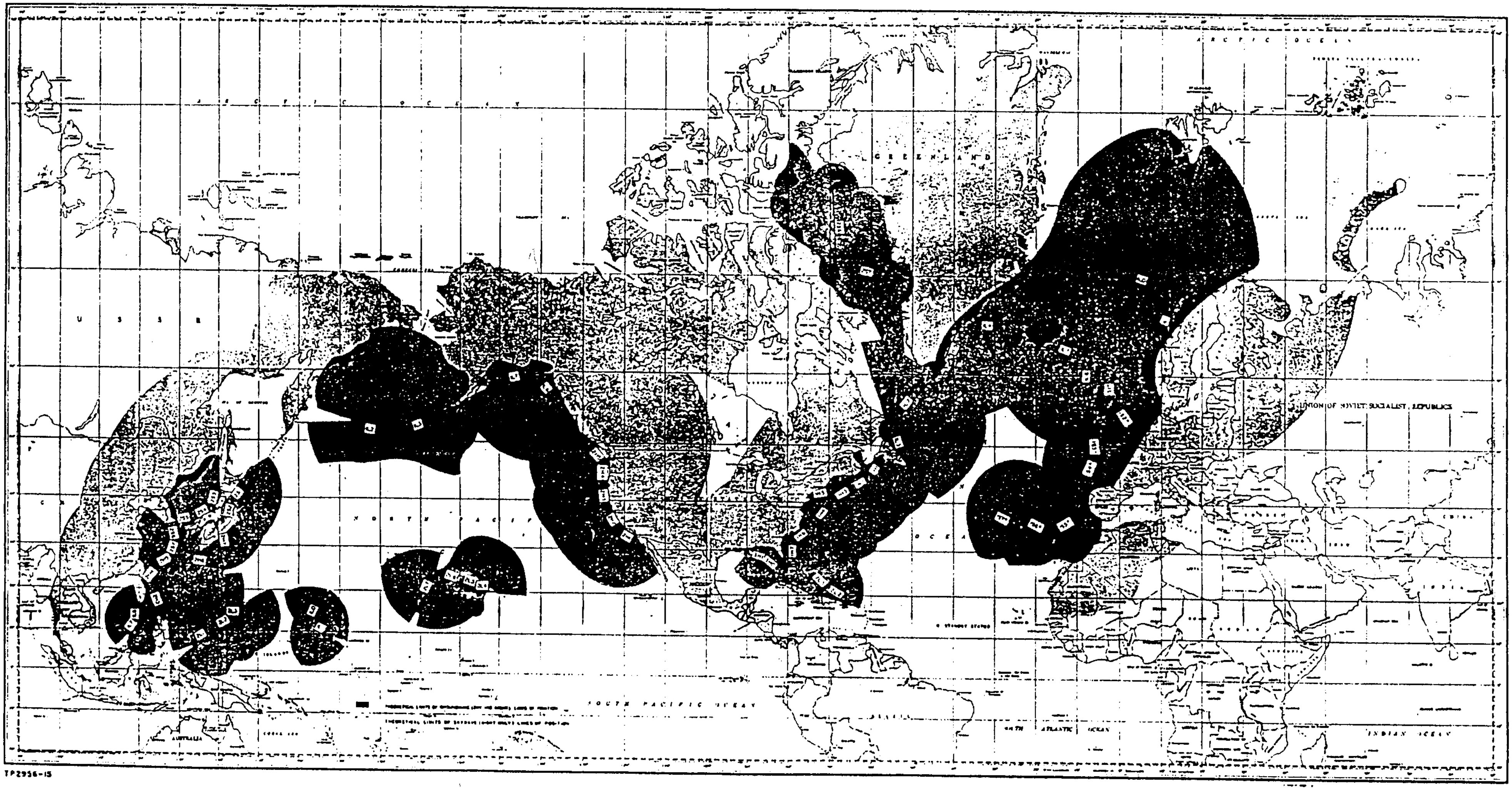



FIGURE 2   Area over which SS Loran was available for air navigation during the winter of 1944-1945 at low level and at 20,000 ft.




LORAN-A WORLD COVERAGE MAP

Figure 3

FIGURE 4 Ground-wave field strength over sea water from 25 kw transmitter

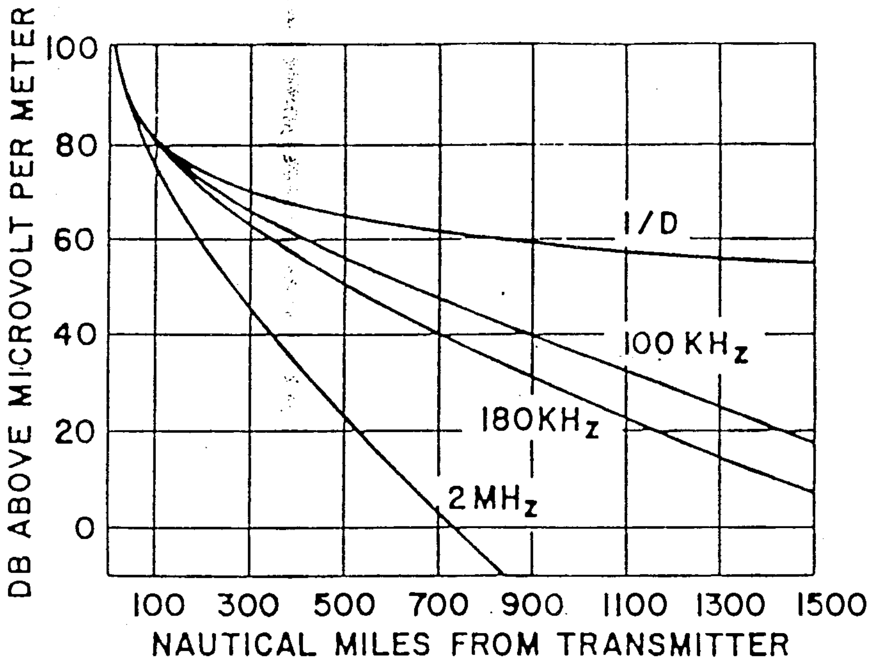
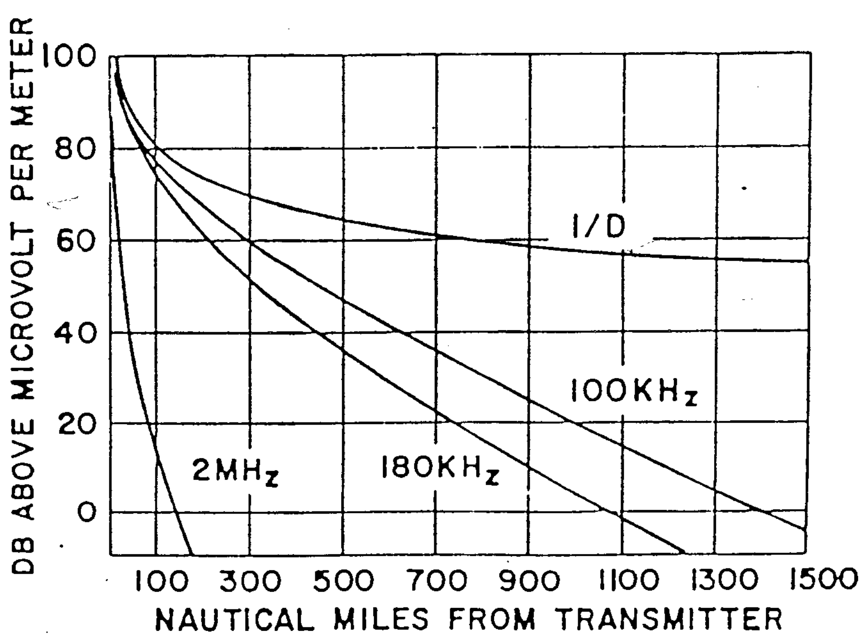



FIGURE 5 Ground-wave field strength over poor earth from 25 kw transmitter



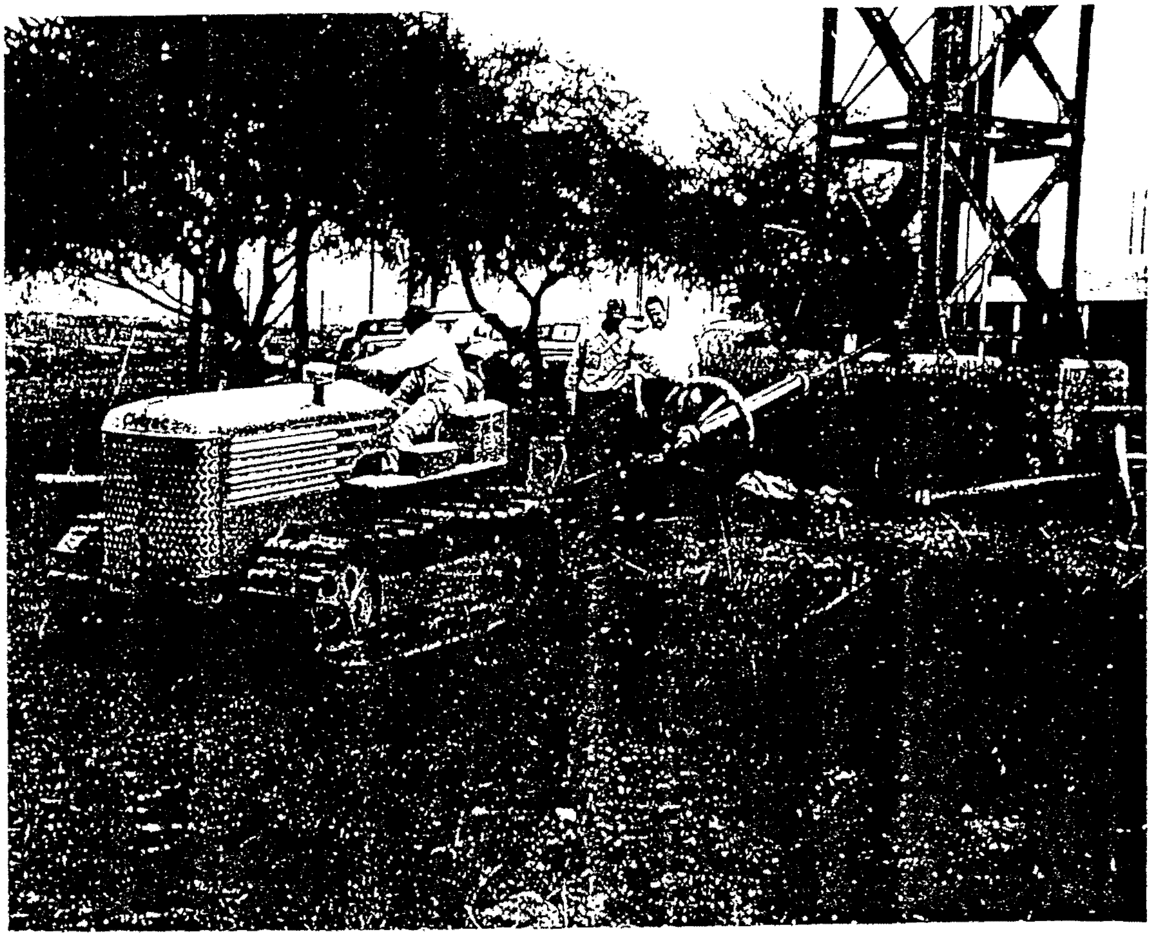
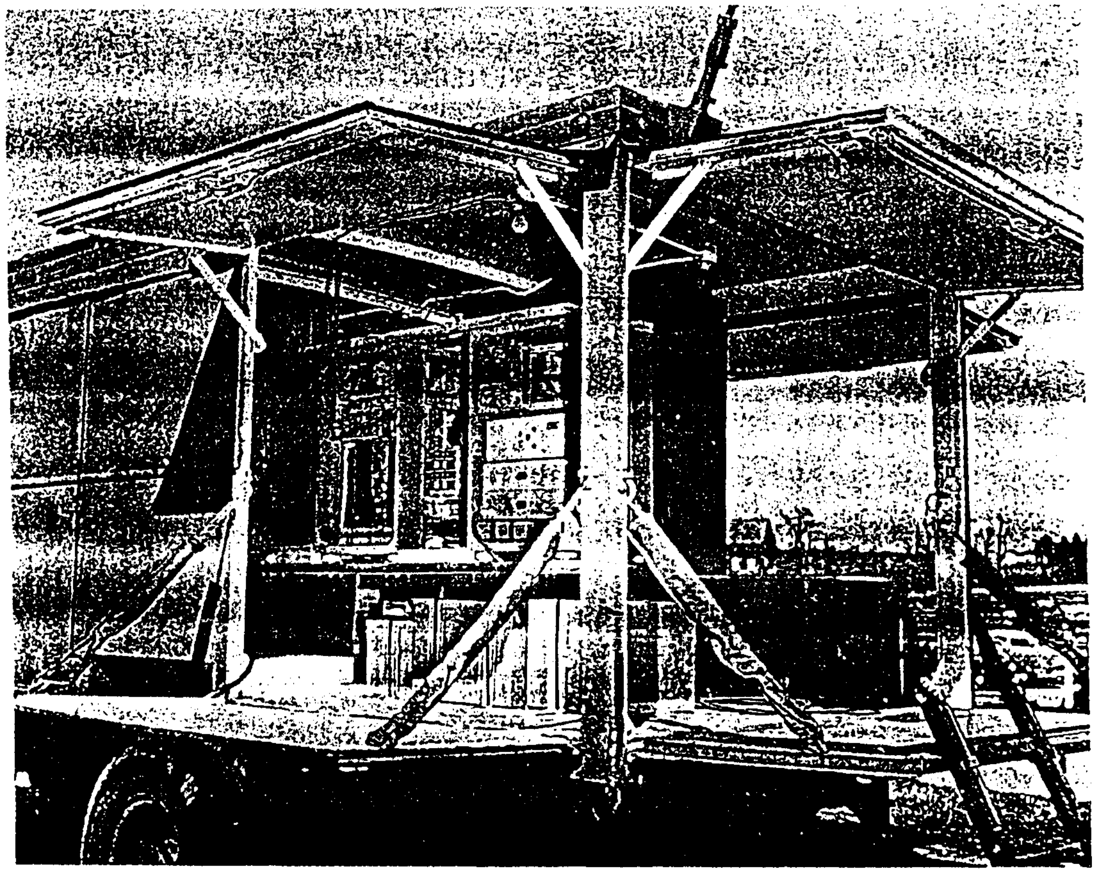


Figure 6 Testing Insulator at Palo Alto Tower



*Cyclan mobile receiver.*

Figure 7

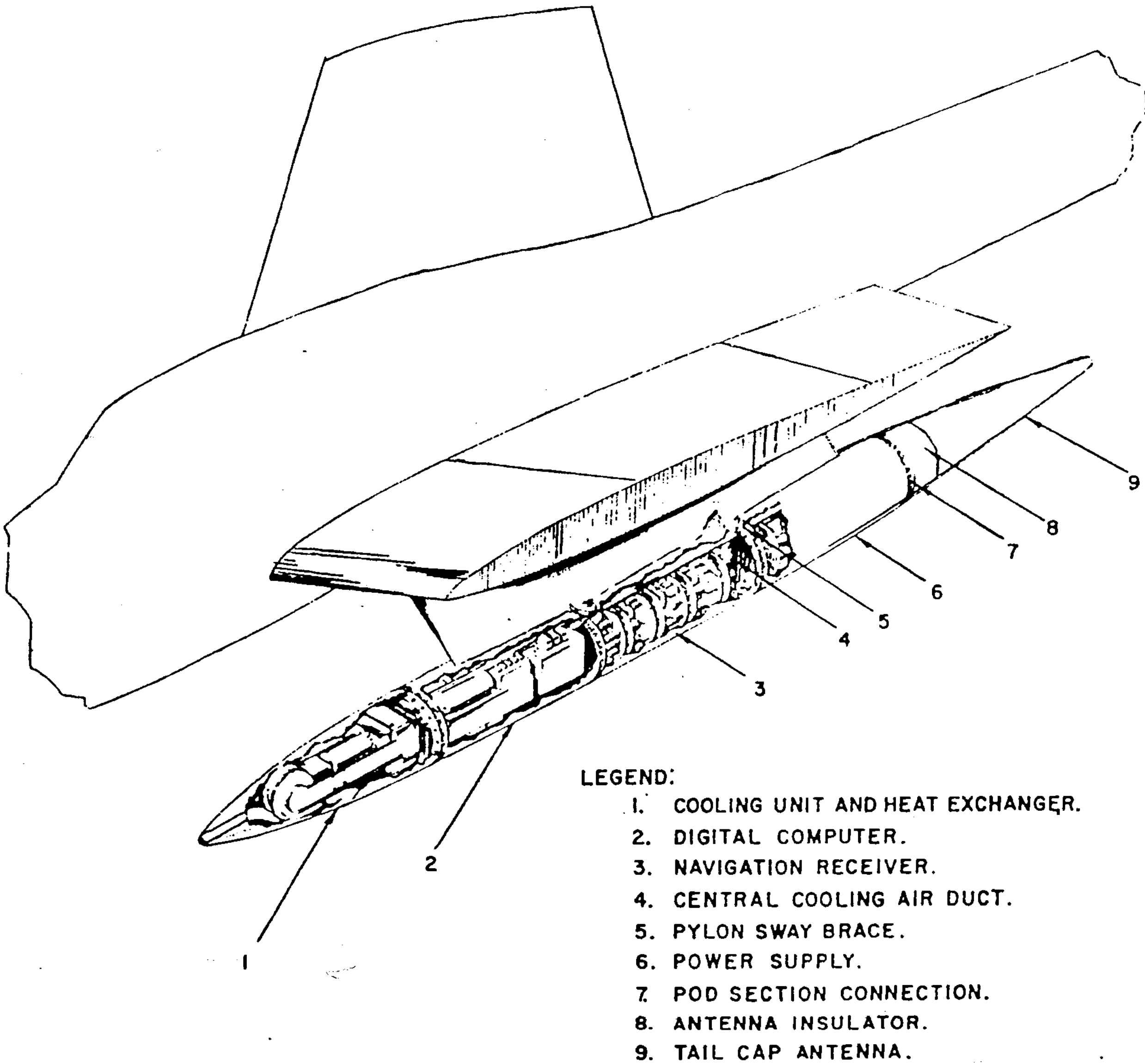



Figure 8 CYTAC Airborne Receiver on F-84

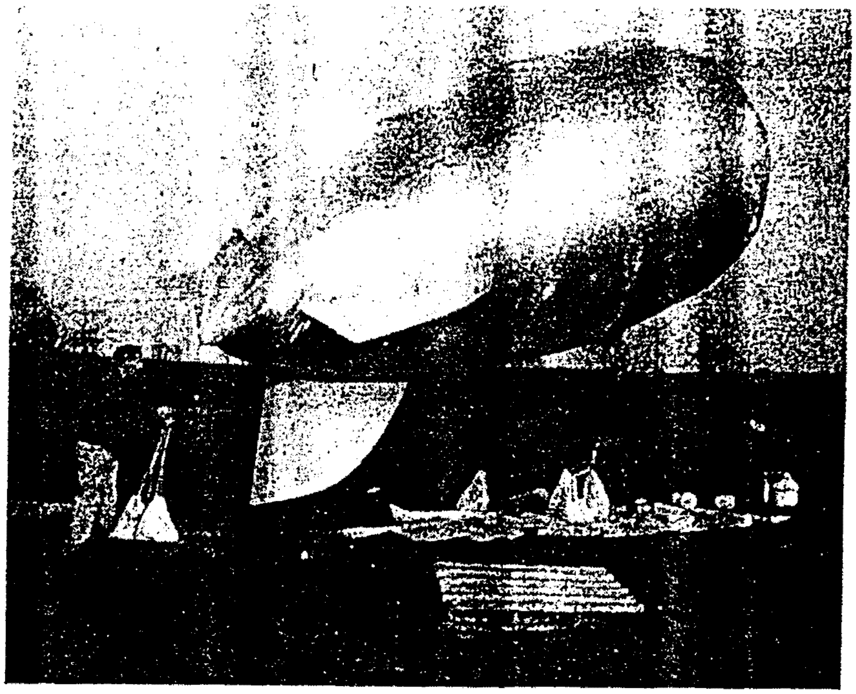


FIGURE 9 Balloon Supporting Antenna at Forestport

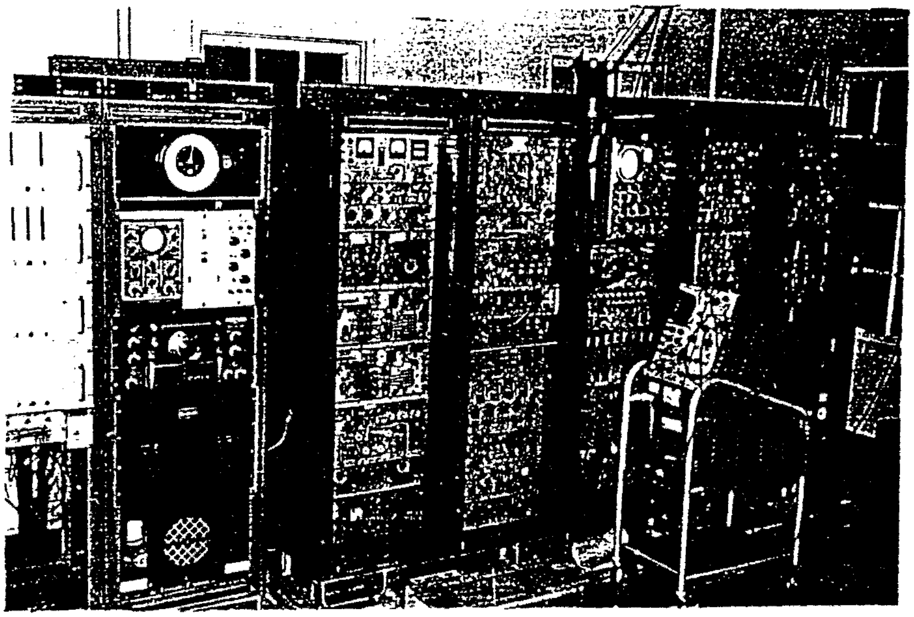


Figure 10  Ground Monitor Receiver at Palmyra

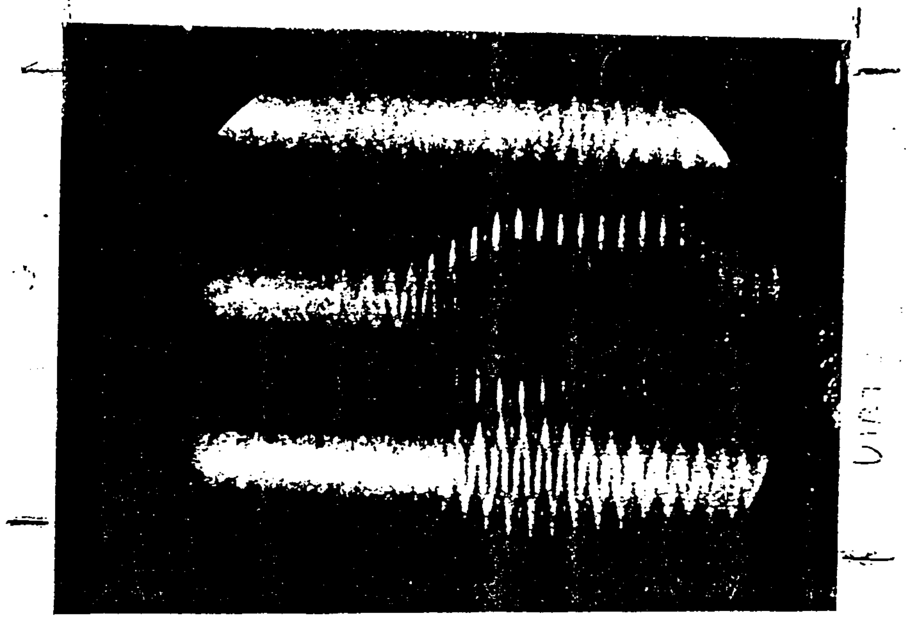


Figure 11 Signals at Natal, Brazil

Figure 12

LORAN C GROUNDWAVE COVERAGE -1967

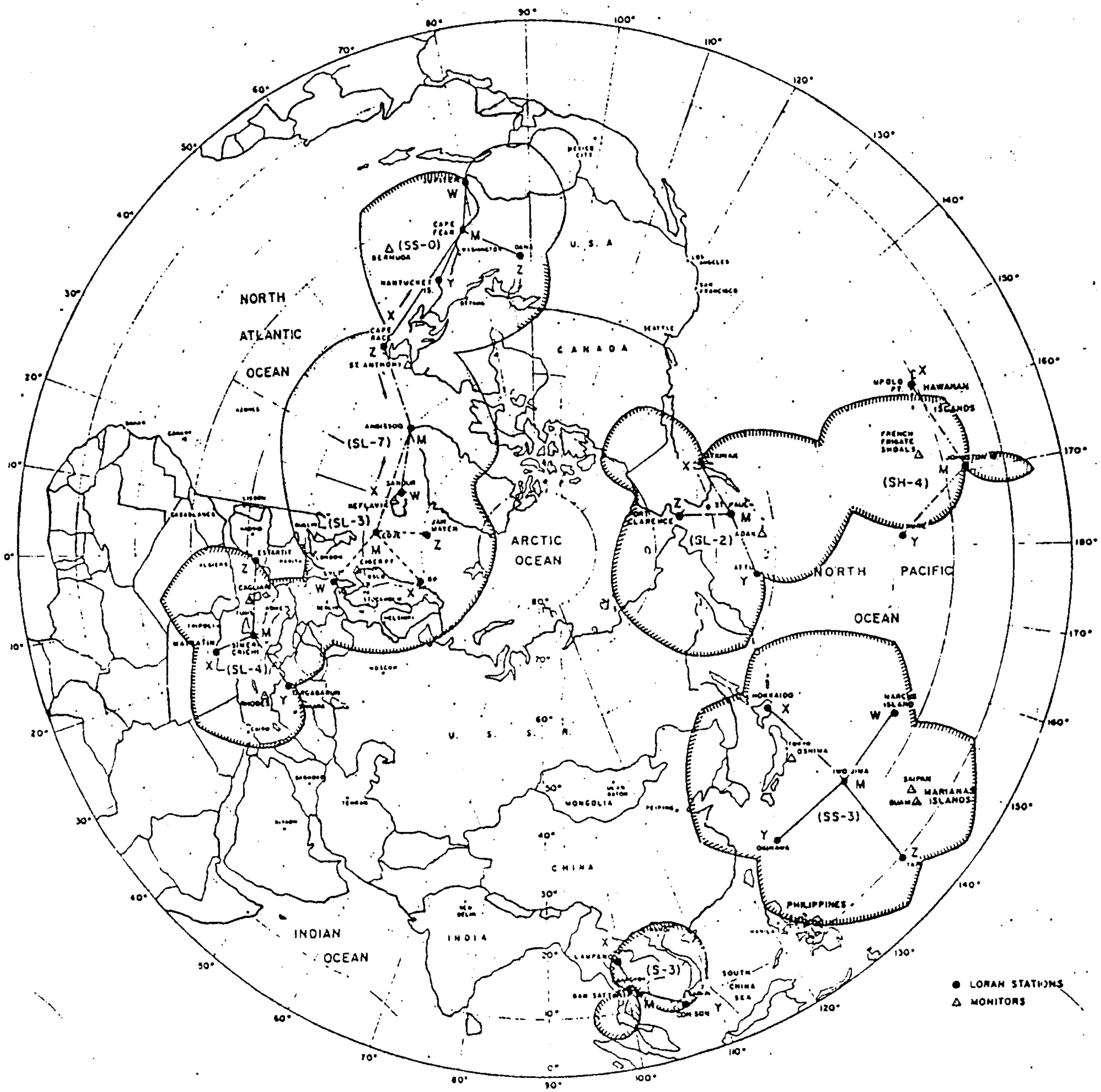


Figure 13

U. S. NAVAL OBSERVATORY
WASHINGTON, D.C. 20390

3 May 1972

DAILY PHASE VALUES SERIES 4

NO. 274

References: (a) Time Service Letter of 30 September 1968, Series 4
(b) Time Service Announcement, Series 9, No. 36
(c) Daily Phase Values, Series 4, No. 195

The table gives: UTC(USNO MC) - Transmitting Station
Unit = one microsecond

| Frequency (kc/s-UTC) | MJD | LORAN-C* Northwest Pacific 100 | LORAN-C* Central Pacific 100 | LORAN-C East Coast U.S.A. 100 | LORAN-C** Norwegian Sea 100 | LORAN-C* Mediterranean Sea 100 | LORAN-C** North Atlantic 100 |
|---|---|---|---|---|---|---|---|
| Apr. 27 | 41434 | 0.6 | 9.5(Note 12) | 3.1 | - 7.2 | 4.1 | 4.5 |
| 28 | 41435 | 0.7 | 9.7 | 3.1 | - 7.4 | 3.7 | 4.4 |
| 29 | 41436 | 0.7 | 9.8 | 3.1 | - 7.4 | 3.6 | 4.4 |
| 30 | 41437 | 0.9 | 10.0 | 2.9 | - 7.4 | 3.6 | 4.3 |
| May 1 | 41438 | 0.6 | 10.0 | 3.0 | - 7.2 | 3.7 | 4.5 |
| 2 | 41439 | 0.8 | 10.0 | 2.9 | - 7.2 | - | 4.5 |
| 3 | 41440 | 0.7 | -- | 3.0 | - 6.9 | - | 4.7 |

| Frequency (kc/s-UTC) | MJD | 8 Ω/NY 10.2 1,000+ | 2 Ω/T 12.0 11,000+ | 3 Ω/H 12.2 25,000+ | 7 Ω/NY 13.6 1,000+ | 6 Ω/H 13.6 25,000+ |
|---|---|---|---|---|---|---|
| Apr. 27 | 41434 | 723 | 593 | 932 | 724 | 934 |
| 28 | 41435 | 722 | 593 | 933 | 724 | 935 |
| 29 | 41436 | 722 | 593 | 932 | 723 | 934 |
| 30 | 41437 | 722 | 593 | 932 | 723 | 934 |
| May 1 | 41438 | 723 | 594 | 933 | 723 | 935 |
| 2 | 41439 | 722 | 593 | 932 | 723 | 934 |
| 3 | 41440 | 722 | --- | 932 | 723 | 934 |

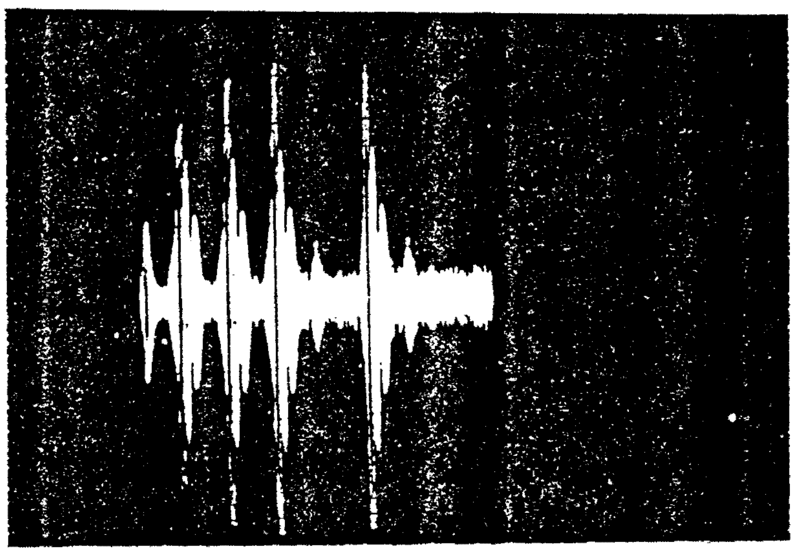


Figure 14 Multiple-Hop Skywaves

# 5

ROBERT FRANK

PREPRINT — HANDED OUT AT CONVENTION

No printed publication — verbal presentation #5

# DEVELOPMENT OF LORAN TECHNIQUES

4 pages

Robert L. Frank
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Great Neck, N.Y.

1st
Wild Goose Association National Convention -
Bedford, Massachusetts, Nov. 30, 1972

I will endeavor in a brief talk today to trace the evolution and development of some of the key techniques which have resulted in the present Loran system.

In the early days, the really new technique that made Loran work was time difference measurement using a locally generated time base. This idea was developed for the G system, and adapted to Loran at the Radiation Laboratory. But in these early systems, the time difference had to be read by a rather complex system of markers on the scope. My first acquaintance with improved Loran techniques was the development of direct dial reading time difference circuits at Sperry by Winslow Palmer and others, which resulted in the model DBE. This receiver actually had been preceeded by a completely automatic tracking experimental unit, but production of that unit was too risky under wartime conditions.

The cycle matching low frequency Loran system as developed by the Radiation Laboratory at the end of the war was a system which again depended upon manually visually matching pulses on an oscilloscope. The first attempt at automation of this process, was in the low frequency Cyclan system. Completely automatic pulse envelop tracking and cycle phase tracking was achieved. The successor of Cyclan was Cytac, a tactical cycle matching long range bombing system.

The slide 1 is a block diagram adapted from the 1952 Cytac proposal which shows the system as it was conceived at that time and as it was actually developed, through field testing in the middle fifties. This diagram shows a number of the key techniques developed during the Cyclan Program. First, is the use of a local oscillator generating a phase reference which is synchronized to the cycles in the master pulse and then phase shifted and synchronized against the cycles in the slave pulse. The calibrated phase shift then provided a measure of phase difference between the master and the slave. The first Cyclan equipment used diode envelop detectors, but early in the program it was recognized that improvements, particularly under poor noise conditions could be achieved by using coherent envelop detection, using a $90^{o}$ shifted version of the cycle reference. This was actually tested in the field for the first time in the later portion of the Cyclan field test. Another crucial element to the success of envelop measuring systems is the utilization of long time constants for the envelop tracking servos. This could not be achieved in the early design because the envelop servo had to actively track the signal in moving vehicles. One of the thoughts developed during the Cyclan program and impemented during Cytac was a cross drive from the cycle tracking servo to the envelop servo, which provided the velocity aid and permitted essentially unlimited time constants in the envelop servos.



Frank - 1-5
[illegible]

The selection of the correct cycle which is based on accurate measurement of the pulse envelop time difference originally in the Cyclan system required the uses of two radio frequencies: 180 KHz and 200 KHz. Later when the carrier frequency was reduced to the present 100 KHz in Cytac, operation would change to single radio frequency channel. An accurate envelop measurements were made possible by the use of an envelop deriver circuit, as shown here in slide 2 in the form used here in Cytac. The incoming signal is amplified, detected in a coherent detector, derivative of the pulse is taken and mixed with the original detected pulse to form a modified pulse which we termed "derived envelop". This is sampled and a servo is driven to the null point on this pulse. Shown in this slide is also a phase reversing technique developed during Cytac known as "synchronous filtering" which greatly reduced d-c offset drift errors in the systems at that time which required the use of vacuum tubes.

Incidently, the possibility of using direct rf sampling both for phase measurements and envelop measurements was investigated in the laboratory in the late forties during the development of the Cyclan system. At that time, the limitations of vacuum tube circuits caused us to adopt the intermediate solution of first coherently detecting the pulse or phase envelop and then sampling. With the development of stable solid state sampling systems most present day receivers are of course using the direct rf sampling.

Another interesting sidelight is the fact that in the Cyclan program use was first made of a rf amplifier type receiver, with the consequence of lack of problems from phase shifts caused by frequency conversions. While we now recognize that the design of such a receiver is quite straightforward, in early Radiation Laboratory days there was trepidation in designing the amplifier having such a large gain on a single radio frequency.

Incidently, the Cyclan receiver used a hard limiting rf amplifier; when the limitations of this type of operation under severe interference was recognized, a conversion was made to a linear rf amplifier for the Cytac system.

Loran has also pushed the state-of-the-art in the area of signal design. Originally in Cyclan the intention had been to transmit the two adjacent radio frequency signals simultaneously, but in the course of development, a decision was made to transmit these successively as a double pulse. An extension of this idea led to multiple pulsing, where the effective duty cycle or average power could be increased relative to peak power by transmitting a burst of pulses from each Loran station. This idea was first implemented in Cytac. A concern in the use of multiple pulsing was that the skywaves from one pulse would fall on succeeding pulses. This was solved by the development during the later part of Cyclan program of the technique known as phase coding. As far as I know the term itself, although now generally used in the information theory art was first applied in the Loran community. Cytac as proposed and implemented uses a burst of eight pulses as shown in slide 3. The phase coding utilized originally for Cytac was an eight-phase code extending over 64 pulses. This code shown in slide 4 was implemented using a three stage binary phase shifter and the design of the code was based on the theory that the phase progression in each column, is equivalent to a different frequency. Thus, each of the eight Cytac pulses could be considered as having an effectively different carrier frequency. This led to the recognition that there would be an eight to one or 18 db rejection of any synchronous cw frequency, and to the further idea, implemented in later Loran-C receivers, that by selective sampling any specific cw frequency could be rejected.

Present Loran-C-D designers are sometimes heard to moan that the Loran timing intervals are not nice binary sub-multiples. During the Cytac program, such numbers were used. The repetition interval was 51,200 μsec, which will be recognized as a binary sub-multiple of 100 KHz, and the pulse separation was 1280 μsec which is also a binary sub-multiple of 100 KHz. However, when the system was converted to Loran in the late 1950's we in our wisdom at that time saw merit in converting back to the standard Loran-A repetition intervals and to changing the pulse spacing to a nice 1,000 μsec which we visualized as the easier to implement in a receiver that was also compatible with Loran-A. Simultaneously, with this change, effort was made to simplify the phase code and a simple binary phase code was developed, which is used at present, requiring only two Loran repetition intervals and utilizing only $0^{o}$ and $180^{o}$ phase shift. We sometime later discovered that a similar binary sequence applied not to phase shift but to slots and blanks was utilized by Golay in an infrared spectometer, and the Loran-C master and slave code have been recently reinvented by people attempting to transmit pulse train as microwave surface acoustic waves.

Another area where Loran has been a leader in the art is in hybrid navigation. Slide 5 bears a very close resemblance to the latest airborne Loran-C/D receivers. You may be surprised to know that it is a slight simplication of a block diagram appearing in the original 1952 Cytac proposal. It shows the marriage of the Loran receiver and a digital computer to perform navigation, guidance, and bomb release functions, with pilot displays and with mixing of air derived data and Loran data. Slide 6 shows in more detail the hybrid signal mixing. It is also a simplification of a diagram appearing in the 1952 Cytac proposal. Shown here is velocity aiding to the Loran tracking servos from air derived data and aiding of the dead reckoning solution by Loran derived data. Included is an auto-pilot loop. The experimental airborne Cytac equipment did actually control an aircraft in flight through the autopilot.

You might be interested in seeing the equipment that was utilized in the early 50's to perform these functions. Slide 7 is a photograph of the experimental airborne receiver mounted in the C-47 aircraft. The shape of the receiver is determined by the fact that at that time we could not see how to get the receiver and its computer inside a small airplane, and had planned to mount it in a bomb shaped pod beneath the aircraft wing. Slide 8 shows the digital computer used in conjunction with the receiver. This was the first airborne digital computer that I know of. It was developed by Hughes Aircraft Co. originally for an aborted short range navigation system known as Digitac and successfully adaptive to Cytac.

In our first public description of the Cytac system which was to become Loran-C, we somewhat with tongue in cheek predicted receiver weight of 40 lbs. based on the transistor which was just then becoming a practical reality, but little did we expect the rapid development of micro-circuit technology which would make our prediction come true with much greater ease and much higher performance than we then anticipated.

Slide 9 shows on the right the first transistorized airborne receiver, the AN/APN-145, and the AN/ARN-78, the first production microcircuit, Loran-C receiver. This had the first real working automatic search. This receiver has several additional innovations in the area of interference rejection. The first was automatic selective sampling to reduce synchronous interference. The first use of manual controlled notch filters for cw rejection in pulse Loran systems was in the Cytac program, and in the ARN-78 the use of transistors and microcircuits finally permitted the development of compact automatic circuits.

I have confined my remarks to some of the early and more fundamental developments. We have of course not slacked our progress in later years. There has been the whole development of transportable Loran-D stations including tactical transportable antennas and solid state transmitters. Another area is marine receivers, where in the early 60's we first demonstrated that crossed loops could be used for underwater Loran reception, and where there has been a continuation of development paralleling the development of aircraft receivers. Loran-A has also continued development from early automatic tracking receivers which were an adaptation of the manual receivers to the presently available simple automatic tracking commercial Loran receivers. I am sure that Loran will continue to push the state of the art in the application and development of new techniques and new technologies to improve system performance, and with reduction in size, weight, and hopefully cost.

* * * * * * * * *

Illustrations similar to the slides may be found as follows:

| Slide No. | |
|---|---|
| 1 | R. Frank, "A Precision Multipurpose Radio Navigation System: Part III, Instrumentation" IRE National Convention Record part 8, 1957. Figure 2 |
| 2 | Ibid. Figure 3 |
| 3 | R. Frank "Multiple Pulse and Phase Code Modulation in the Loran C System" IRE Trans. ANE. June 1960, Figure 1a. |
| 4 | R. Frank and S. Zadoff "Phase Shift Codes with Good Periodic Correlation Properties" IRE Trans. IT, Oct. 1962 p. 381-382 |
| 5 | S. Zadoff and J. Rattner "Use of a Digital Computer for Airborne Navigation and Guidance" 1957 Eastern Joint Computer Conference. Figure 2 |
| 6 | Ibid. Figure 4 |
| 7 | E. Durbin "Current Developments in the Loran C System" Navigation (USA) Summer 1962 |
| 8 | Ibid. |
| 9 | Ibid. |

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3/20/89

This is the way the program was handed out. If you want copies of actual figures, I can dig them up

Bob Frank

#6

JOHN HOPKINS

Wild Goose Assn 1st Nat'l Conv Nov 1972 #6

RLF

# TELEDYNE SYSTEMS COMPANY
# NORTHRIDGE CALIFORNIA

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ROBERT L. FRANK
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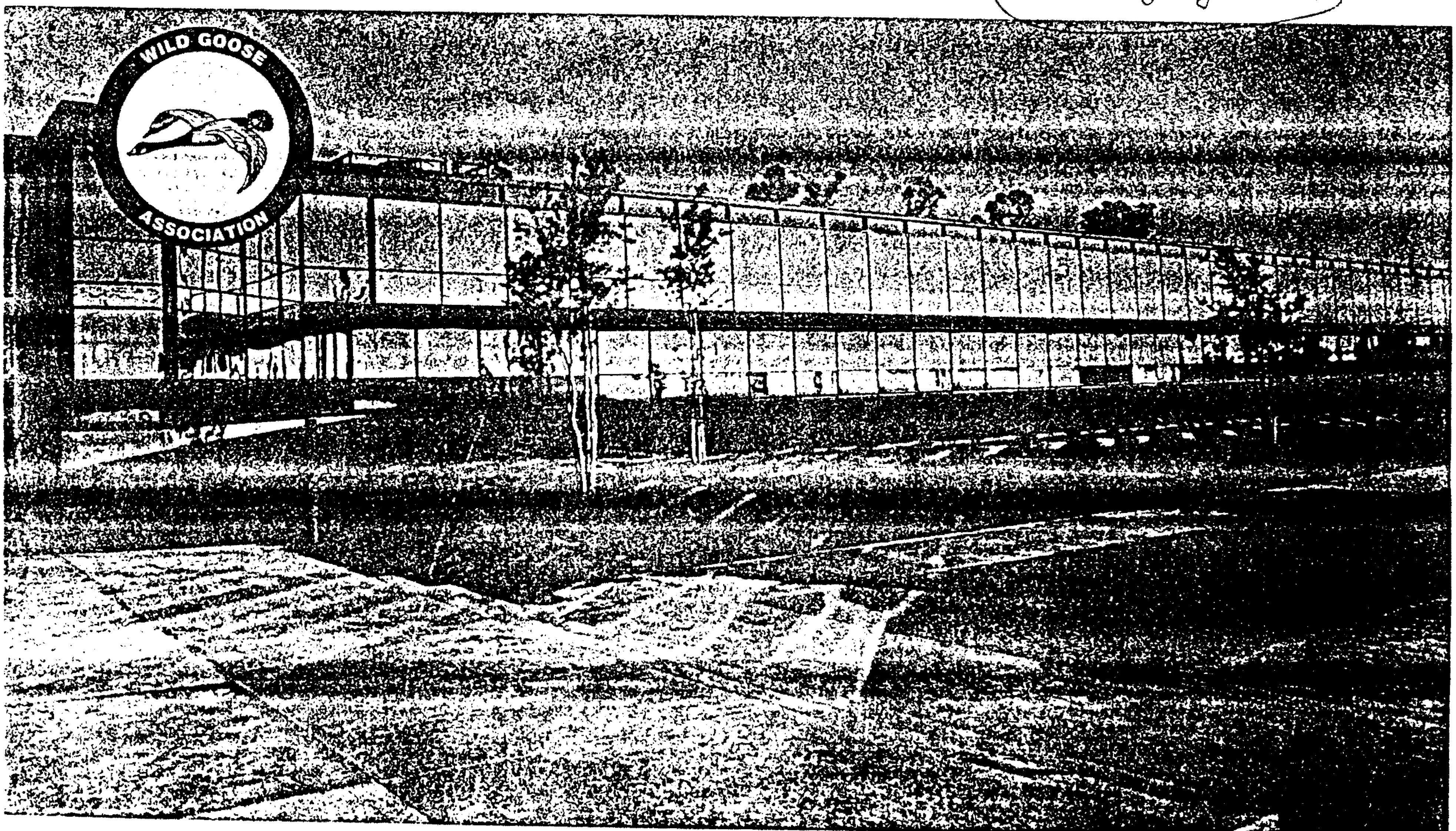
2 pages



# TELEDYNE SYSTEMS COMPANY
# NORTHRIDGE, CALIFORNIA

NOV. 1972

TELEDYNE SYSTEMS COMPANY
19601 Nordhoff St. • Northridge, Calif. 91324

03019

SECOND GENERATION LORAN C RECEIVERS
Chronicle and Commentary
By
John Hopkins, Teledyne Systems Company

## INTRODUCTION

In the evolution of LORAN C, we are experiencing a landmark – the impact of second generation LORAN C Receivers. LORAN C has emerged from an era of narrow and limited use to become a versatile system with a myriad of practical applications. This can be attributed to the increased flexibility of second generation receivers and to the successful LORAN C operations in Southeast Asia which focused world attention on the utility and value of the system. As a direct result, the U.S. Air Force and Army made major commitments to employ LORAN C/D in nearly every type of tactical and strategic operation where they need precise position information. The Navy, thus far, has concentrated its use of LORAN C on submarines. All three services have active funded developments underway to upgrade their LORAN C Systems. In addition, the U.S. Coast Guard has funded the development of low cost commercial LORAN C Receivers for marine applications. They have also proposed the adoption of LORAN C as the Coastal/Confluence National Navigation System.

This paper attempts to capture this landmark period in the evolution of LORAN C by providing commentary on the state of second generation LORAN C Receivers – design and development, accomplishments and applications, problems and trends.

## DESIGN

LORAN C, as we know it, has been with us about 13 years. During most of this period, nearly a decade, the fundamental design philosophy of the receiving equipment was changed very little except for routine progressions from tubes to transistors, manual to automatic, and an emerging emphasis on digital processing. The culmination of this era was the AN/ARN-92 which is the most sophisticated LORAN C System of what has become known as first generation LORAN C Systems. All these first generation systems were linear. They required a long warmup time, and an external velocity aid to search and settle during maneuvers. They were sensitive to envelope distortion and had search and settle times approaching 15 minutes. And, probably as a result of their marine oriented background, they had heavily damped tracking loops.

These first generation designs were also influenced by procurement specifications which relied on convenient laboratory tests to measure system performance. The specs and, therefore, the designs did not properly account for real world noise, envelope distortion and interference conditions. In effect, the emphasis on simple and sometimes unrealistic laboratory tests resulted in real world design inadequacies and excesses. Various attempts have been made to bring the laboratory tests in line with the real world but so far it remains an unfulfilled goal in spite of many well intended LORAN simulator programs. Perhaps, the GRN-99 LORAN Simulator has the capability to solve this problem. The most serious limitations of the first generation designs, however, were size and cost.

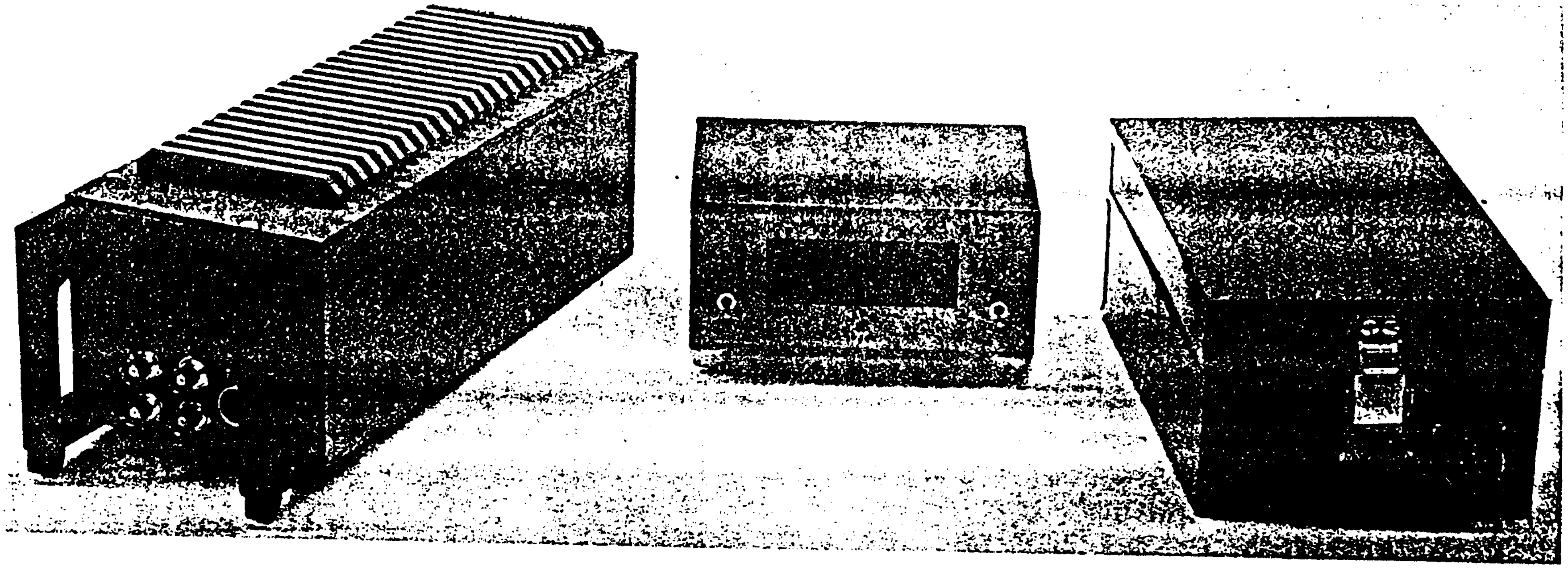
The ARN-92 LORAN Navigation Set is in the 100 pound/$100K class; thus, its use was restricted to special applications, such as the Pave Phantom and Igloo White Programs, where this size and cost could be justified. All of use can be grateful it performed well in SEA, not only because it improved our RECCE and STRIKE capabilities but also because it materially enhanced the reputation of LORAN C. However, to satisfy the larger need for accurate positioning, much simpler and cheaper designs were required. There was also room for performance improvement, particularly start-up time, dynamic operation and cycle selection. And, for military applications more effective ECCM was also required.

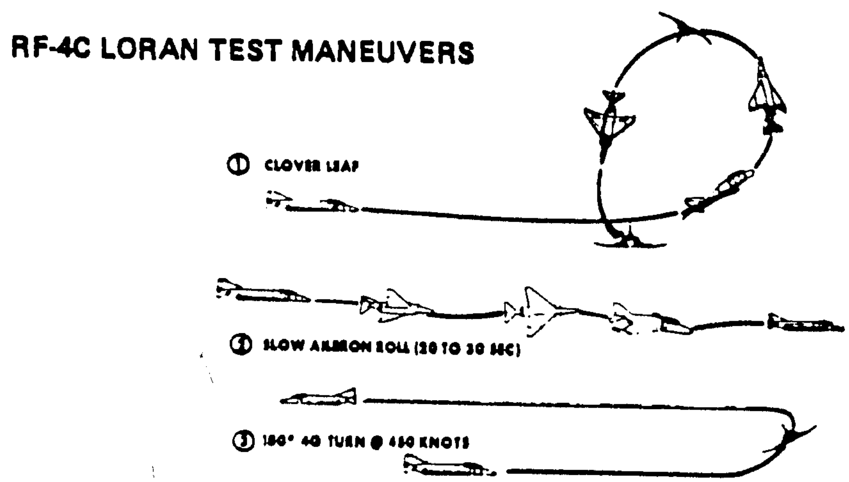
The second generation of LORAN C Receivers was born to satisfy these requirements. Through design innovations and higher density microelectronics, LORAN C Receiver costs were slashed, many critical and expensive parts were eliminated, the overall parts count was reduced and performance was improved. Moreover, where similarity of design is the hallmark of the first generation of LORAN C Receivers, variety is the mark of the second generation. Figure 1 illustrates this contrast. Fortunately, this variety enables designs ranging from very simple forms to those far more sophisticated than first generation systems, and still retains the characteristic cost savings of second generation designs. Because of this design variety, there are now many ways to design a LORAN C Receiver and this prompts some lively debates. One of the most interesting controversies arose over the concept of hardlimiting. It almost took on quasi religious overtones. The establishment vigorously attacked hardlimiting as a design heresy and the LORAN world divided into two camps - Linear and Hardlimited. The linear establishment launched a barrage of academic reasons alleging certain deficiencies in hardlimiting which could be demonstrated in the laboratory. The hardlimiting advocates fought back, not by debating the theory but rather by the very pragmatic approach of compiling an outstanding performance record in the real world in every sort of field environment. The alleged shortcomings of hardlimiting simply did not show up in day-to-day real world operations. In the face of successful hardlimited receiver designs, the linear establishment allowed that hardlimiting might be satisfactory for manpacks but not for high performance aircraft. There is no real basis for this claim. To demonstrate this, Teledyne installed a manpack receiver weighing only 7-1/2 pounds (Figure 2) in an Eglin AFB RF-4C two years ago and flew it through high G maneuvers. It was not velocity aided. Several signal acquisition tests were performed at speeds from 150 to 500 knots and the average search and settle time was 2-1/2 minutes. It did not lose lock in any maneuvers. We believe this proved the point. Somewhat more troublesome was the allegation that hardlimited receivers experience a dead band when the skywave delay is exactly 1000 μseconds. This is theoretically true, but in the real world we have been unable to detect it in spite of thousands of hours of operating experience in areas where this condition is alleged to occur. It is either too brief to be noticed or accompanied by so much atmospheric noise as to diminish the effect to insignificance. Or, could it be that this

# DESIGNERS' CHOICE

| FIRST GENERATION<br>COMMON PARAMETERS | SECOND GENERATION<br>TAKE FOUR FROM COLUMN A | <br>FOUR FROM COLUMN B |
|---|---|---|
| COMPLETE RECEIVER<br>NOTCH FILTERS | COMPLETE RECEIVER<br>OR<br>FRONT END | DISTRIBUTED LOGIC PROCESSOR<br>OR<br>CENTRAL PROCESSOR |
| NARROW TRACKING BW<br>LINEAR | NOTCH FILTERS<br>OR<br>STEEP BAND PASS FILTERS | HYPERBOLIC<br>OR<br>DIRECT RANGING |
| DEDICATED PROCESSOR<br>HYPERBOLIC | NARROW TRACKING BW<br>OR<br>WIDE TRACKING | SINGLE STROBE SAMPLING<br>OR<br>MULTIPLE STROBE SAMPLING |
| SINGLE POINT STROBING<br>STANDARD CIRCUITS | LINEAR<br>OR<br>HARD LIMITED | STANDARD CIRCUITS<br>OR<br>CUSTOM CIRCUITS |
| | SUBSTITUTIONS, HYBRIDS, OR COMPROMISES ARE ACCEPTABLE | |

Figure 1






# MARK I LORAN C/D RECEIVER

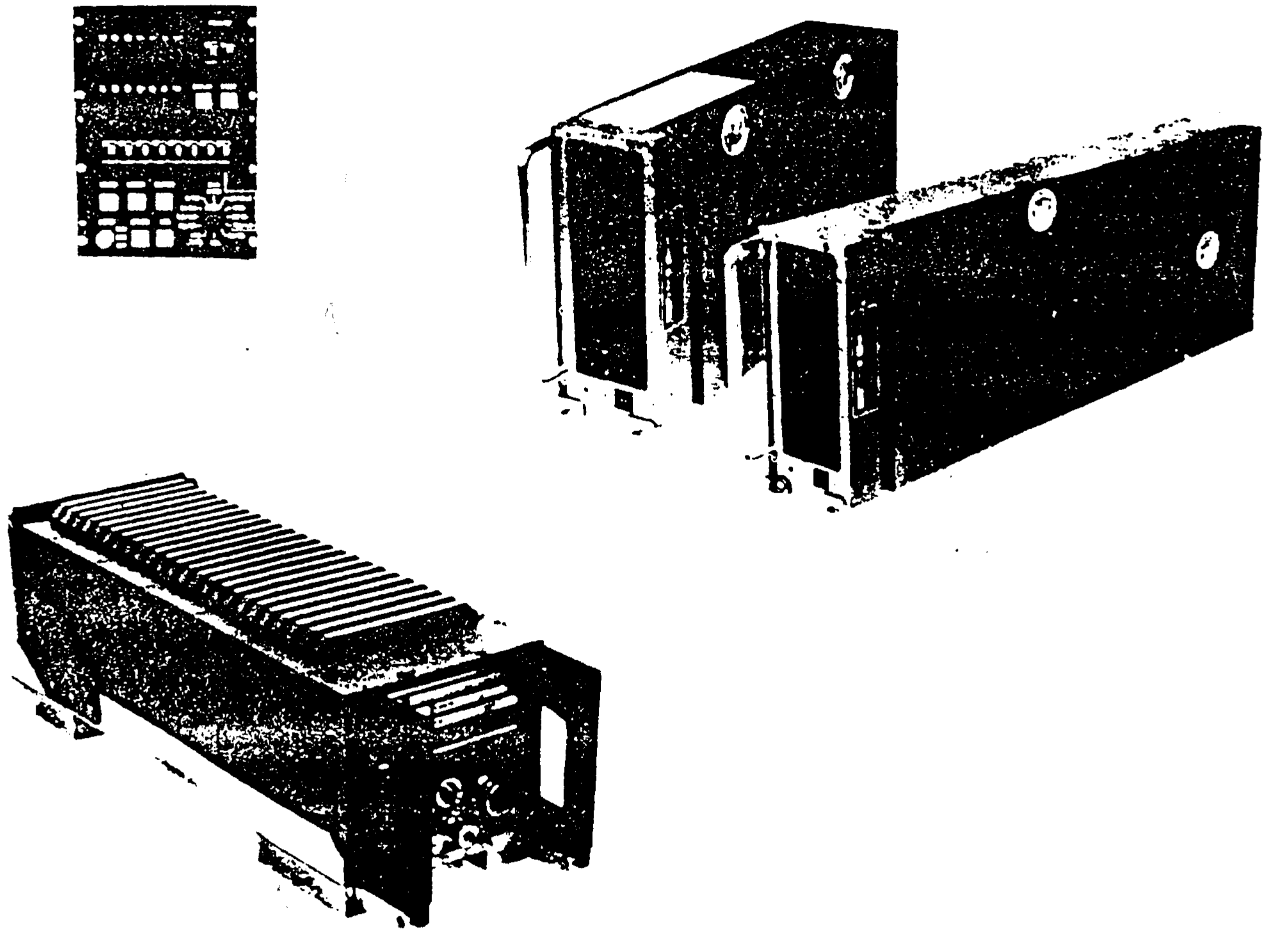
## HIGH PERFORMANCE FLIGHT DEMONSTRATION (OCT. 1970)

Figure 2

phenomenon never really occurs at all? In any event, in our experience, the problem is mythical. We affectionately call it the Lock Ness monster and, just in case specifications call out a laboratory test for this condition, we have designed a Lock Ness monster killer to augment the basic hardlimiter. Another troublesome and related charge was that hardlimiting was more susceptible to continuous wave interference. This allegation is particularly frustrating, again because it is theoretically true. However, it is easily overcome by using notch filters. In practice, linear receivers need and use as many and sometimes more notches than harlimited receivers so this alleged disadvantage of the hardlimiter is more emotional than it is real. Of course, in the final analysis there is merit on both sides and some designers have resorted to hybrid approaches to have the best of both worlds. The question remains, "Is it worth it?" I don't believe it is. The hardlimited approach has proven to be an excellent match to the actual real world environment. Unfortunately, specifications are still written in terms of laboratory tests which are frequently unrealistic. Interestingly, the linear establishment prevailed in the recent ARN-101 and ARN-(  ) competition at ESD, but at ECOM and Coast Guard the relative simplicity of the hardlimited design, along with its successful field test record, proved more attractive.

Another important design innovation which is being perfected by Teledyne under Air Force sponsorship is Direct Ranging LORAN, also called DRL. DRL is a rho-rho-rho system and involves measuring changes in range from three transmitters. Since one measurement is redundant, a recursive filter mechanization will provide an estimate of clock phase error and drift. Like hyperbolic LORAN, no initialization is necessary. When first turned on, DRL accuracy and hyperbolic accuracy are exactly equivalent, but in a short time the clock errors are estimated and the position estimate is refined. DRL provides greater accuracy in all parts of the coverage area. In the prime area the improvement is only 10 to 20 percent but in areas where hyperbolic LOP's cross at small angles dramatic improvement, on the order 20 to 1, occurs. This has been verified in instrumented flight tests at Eglin AFB (Figure 3). This significantly increases the useable coverage area by providing reasonable accuracy in the area of the baseline extensions and on the reverse side of the triad. Figure 4 shows the effects of geometric factors on the CEP for 100 foot repeatability measurement errors and Figure 5A and 5B show the effects on worldwide coverage.

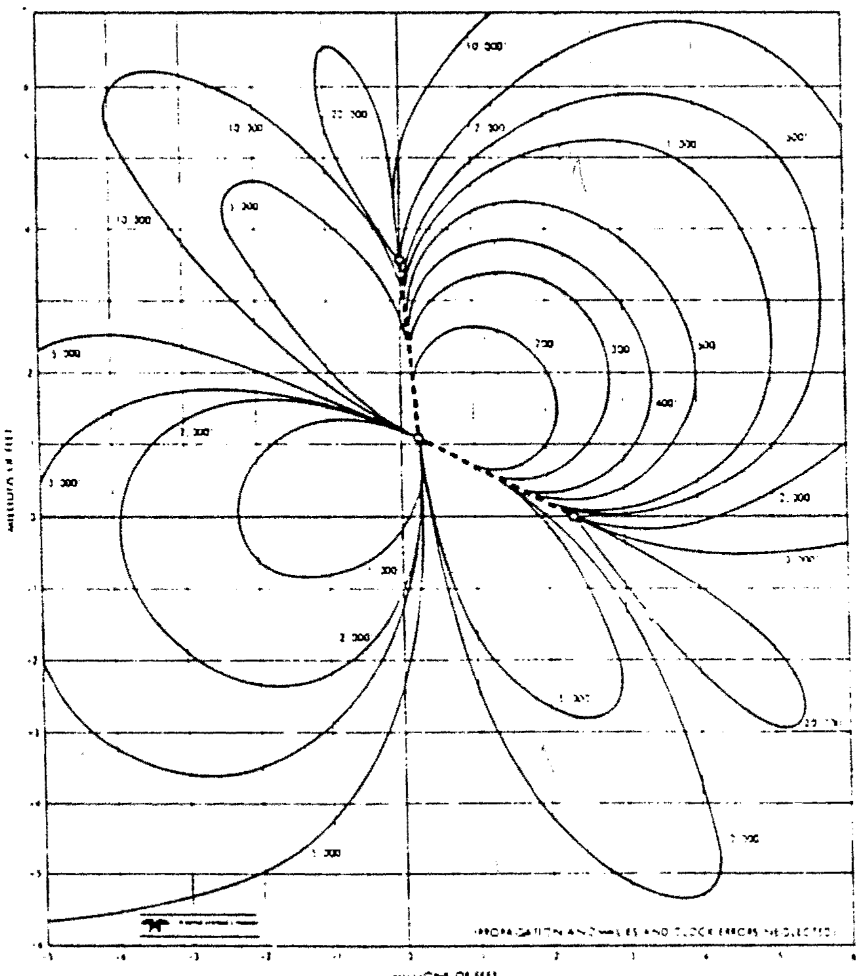
One must be careful not to confuse DRL with the rho-rho mechanization which is vastly different and does not provide the many benefits of the DRL rho-rho-rho mechanization. Rho-rho systems measure the change in range from two transmitters. They depend for accuracy on a highly stable (expensive) on board clock which may or may not be phase synchronized with the transmitter clocks. It is used in special applications such as propagation studies and off shore differential positioning. To highlight the difference we sometimes say that in DRL you rho-rho-rho your clock. There are other advantages of DRL that go beyond this talk. For those of you who are interested we would be pleased to give you appropriate references.



DIRECT RANGING LORAN SYSTEM

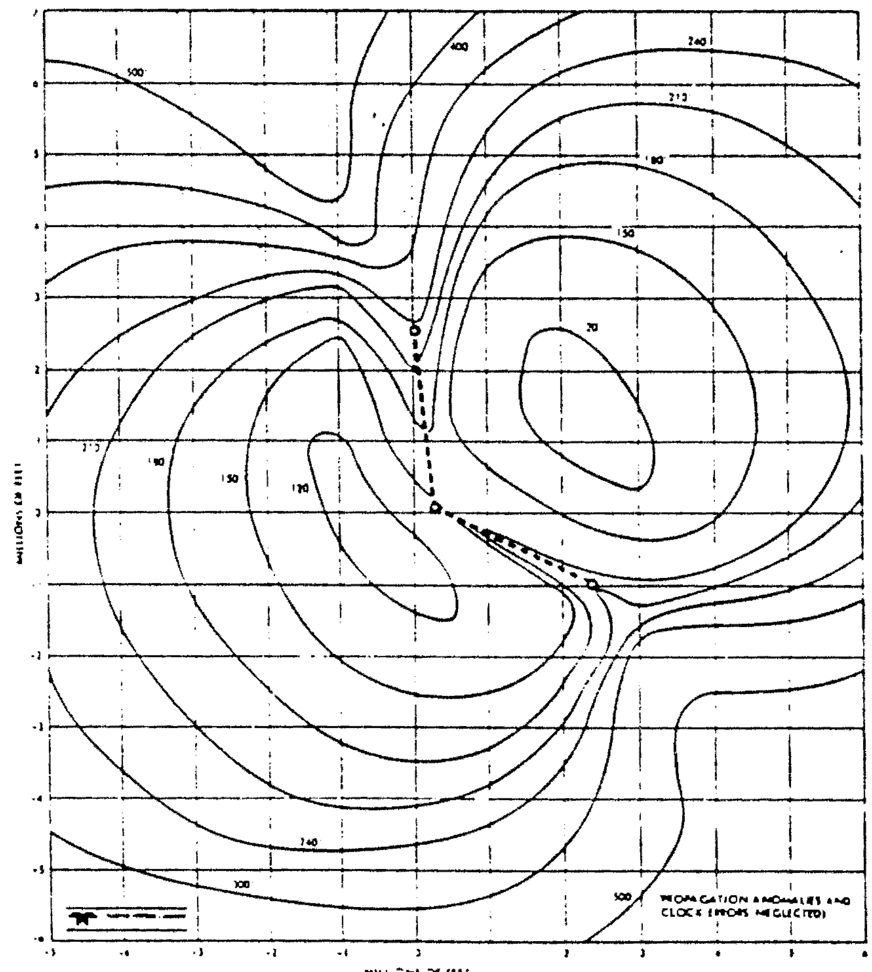
Figure 3

**CONTOURS OF CONSTANT RADIAL ERROR**
**LORAN HYPERBOLIC SYSTEM**
**100FT. (1σ) REPEATABILITY/AXIS**



T32244

**CONTOURS OF CONSTANT RADIAL ERROR**
**BIMODAL LORAN DIRECT RANGING SYSTEM**
**100FT (1σ) REPEATABILITY/AXIS**

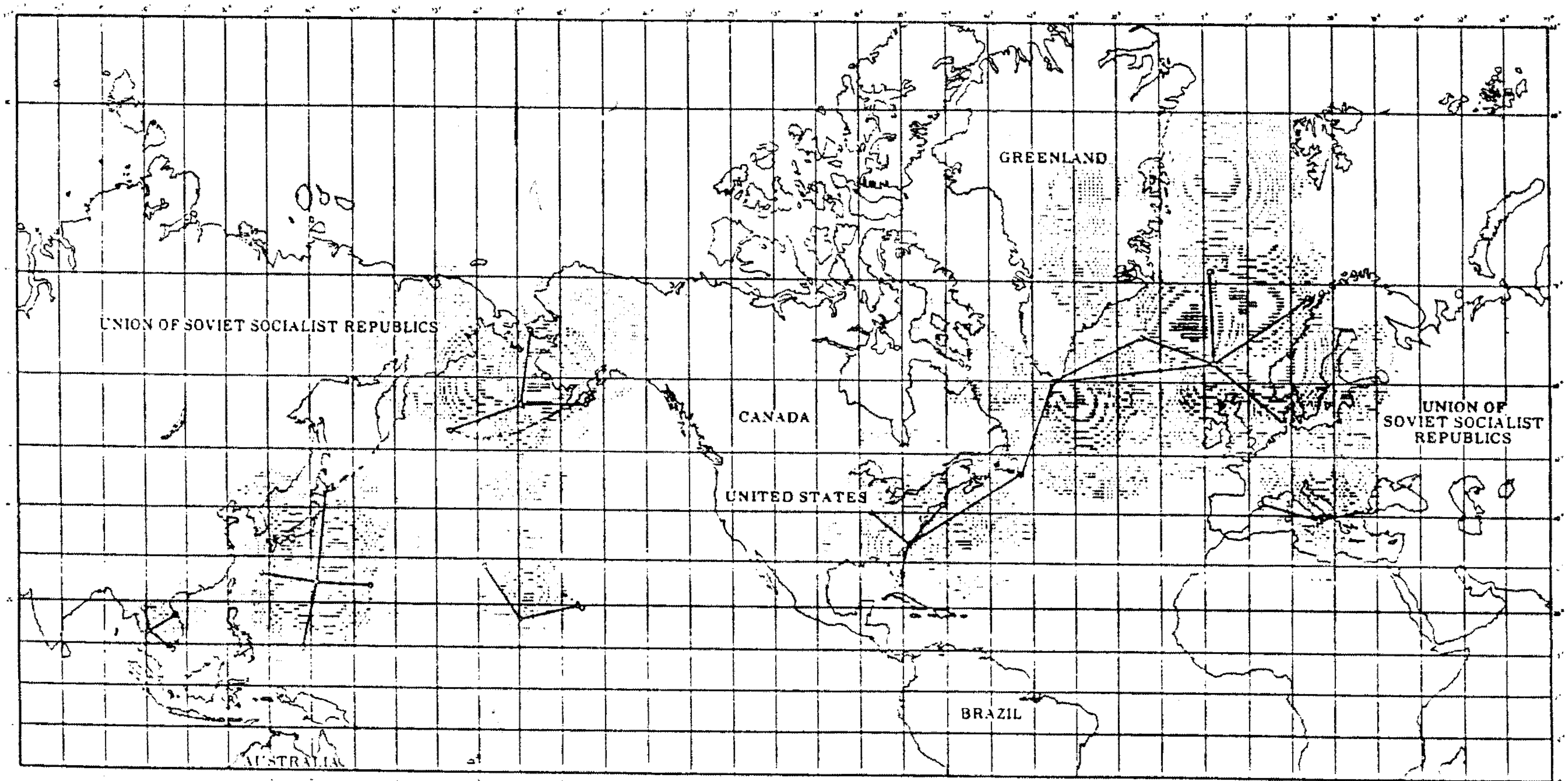


T32243

Figure 4

# WORLD LORAN COVERAGE

HYPERBOLIC




SYSTEMS COMPANY

SHADED AREAS ARE WHERE AIRBORNE ACCURACY IS BETTER THAN 500 FEET ONE SIGMA

CHAIN STABILITY $\approx$ 50 ns ONE SIGMA
TOTAL NOISE = 200 $\mu$V/ METER
RANDOM AIRCRAFT ACCELERATION $\approx$ .5g ONE SIGMA
T = 10 SEC

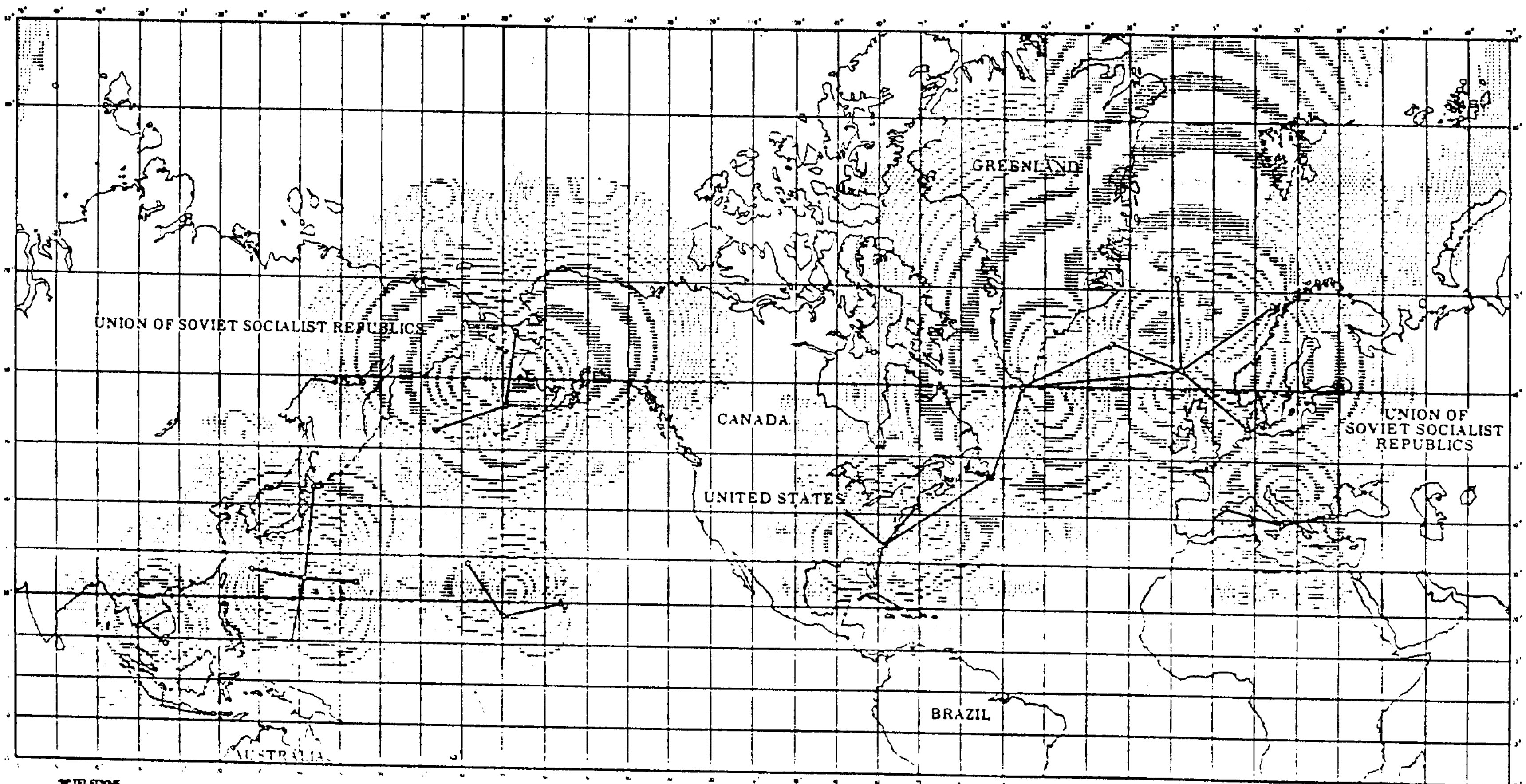
771563

Figure 5A

## WORLD LORAN COVERAGE

**DIRECT RANGING**

CLOCK CALIBRATION= 330ns ONE SIGMA




TELEDYNE SYSTEMS COMPANY

SHADED AREAS ARE WHERE AIRBORNE ACCURACY IS BETTER THAN 500 FEET ONE SIGMA.

CHAIN STABILITY = 50ns ONE SIGMA
TOTAL NOISE = 200 μV/METER
RANDOM AIRCRAFT ACCELERATION = .5g ONE SIGMA
T = 10 SEC

771562

Figure 5B

## DEVELOPMENT

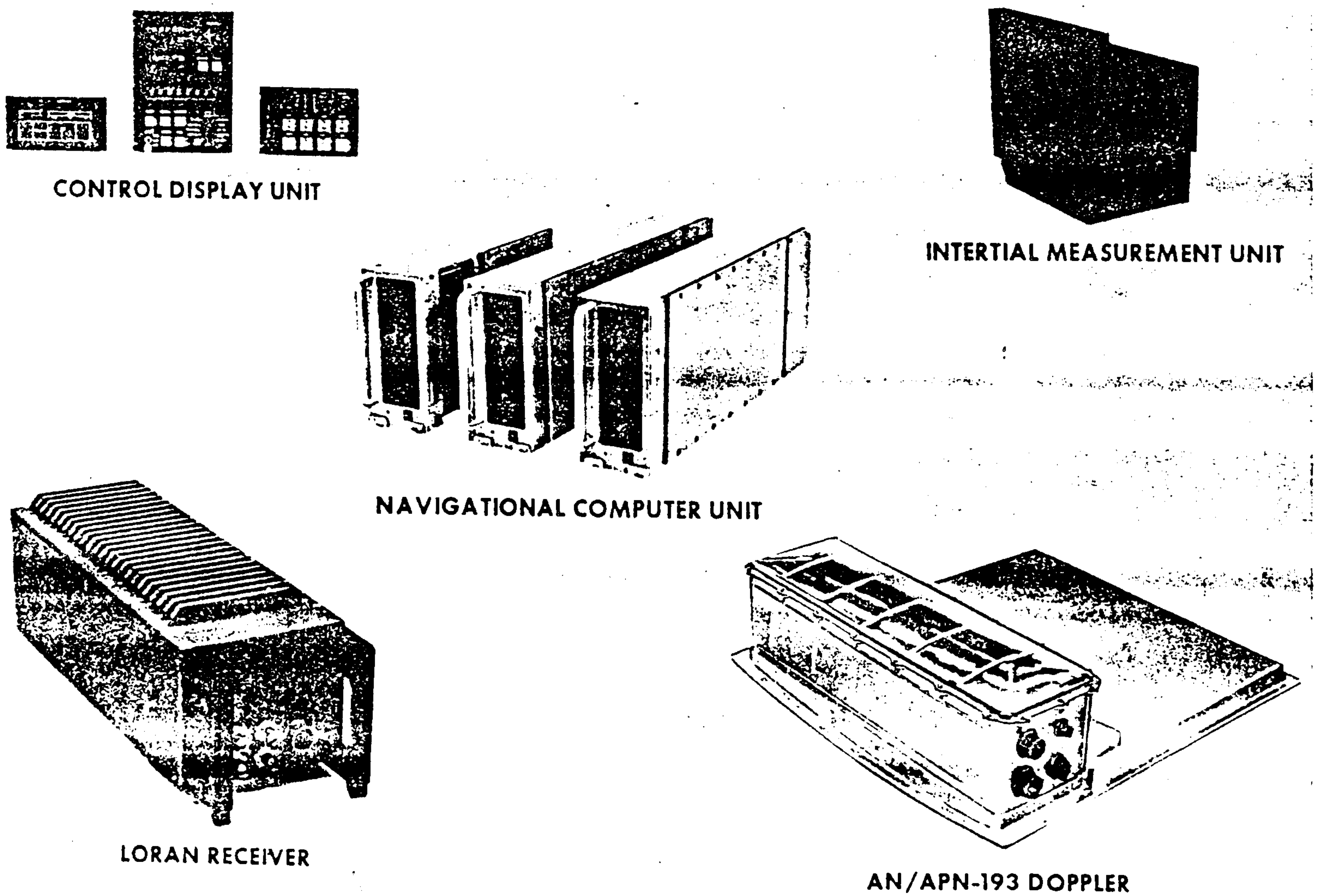
To my mind the beginning of second generation LORAN C Receiver development coincided with the Air Force's interest in and sponsorship of the Integrated Doppler Inertial LORAN Navigation System popularly known as the DIL Program. The objective of the DIL Program was to develop a system suitable for high performance fighter aircraft that weighed less than 100 pounds and cost less than $100K (Figure 6). Since a fighter might have to be over the target in less than 15 minutes from alert, fast reaction time was mandatory. Moreover, this mission demands precise instantaneous velocity and position. Therefore, optimal filtering techniques were necessary to fully exploit the synergetic properties of the DIL sensors. First generation LORAN C Receivers were clearly inadequate for the DIL System; so two of the competing companies, Teledyne and Litton, developed new receivers. Both were hardlimited receivers. The Teledyne receiver, the TDL-101, contained a dedicated processor for mode control and time difference computations. It was fully automatic and weighed only five pounds (Figure 7). The Litton receiver contained the RF front end and a preprocessor. It relied on a general purpose computer for mode control and time difference computations. These receivers were successfully flown at Eglin AFB in 1970. Different government agencies became interested and funded a variety of configurations to satisfy their special needs. This led to a family of systems which all derived from the same design (Figure 8). This is a complete fully automatic receiver and weighs only 3 pounds 3 ounces. Figure 9 shows the chronological development of this receiver. Some of the other second generation systems produced by Teledyne are shown in Figure 10. Litton's family album would contain such entries as the UPN-35, Helnav, LRN-102, and the low cost LCR-301.

This is not to say that only Teledyne and Litton have produced second generation LORAN C Systems but they have produced the preponderance of systems in this category. New development efforts by other companies are also being presented to this audience today. In 1973 we should see the results of the Army's PSN-6 and LANS developments and the Air Force's ARN-101 developments.

By the way, the casual observer is probably unaware of the excitement that underlies these developments. The suspense and intrigue connected with competitive procurements these days and fly before buy run-offs produce the tenseness of a spy thriller with visits from the OSI and inquiries from the GAO thrown in to lend realism. I suppose this has to be expected when survival is at stake and that is the name of the game, since no further government sponsored developments are in the offing – the boat has sailed. For those not aboard, it will be extremely difficult and for those who have development contracts plenty of anxious moments lie ahead. In just the past two months, budget problems resulted in three significant LORAN Programs being cancelled or indefinitely postponed: The ARN-( ), the Integrated LORAN Omega and the Aerial Scout Programs. These are perilous times and yet times of great opportunity.

## ACCOMPLISHMENTS AND APPLICATIONS

As a result of LORAN C accomplishments in SEA and the obvious attributes of the second generation designs, more and more LORAN C




INTEGRATED DOPPLER INERTIAL
LORAN NAVIGATION SYSTEM

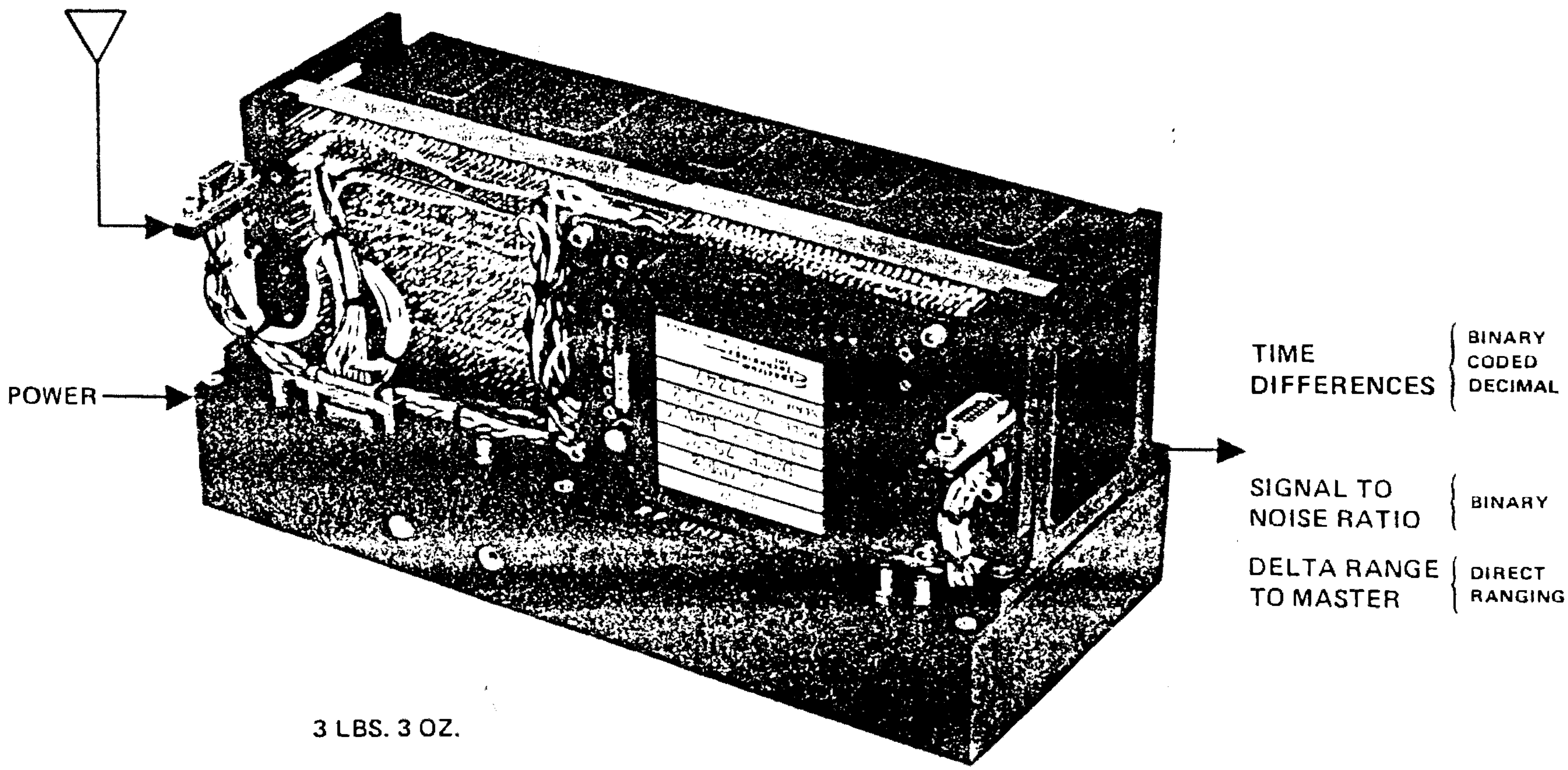
Figure 6

# COMPARISON OF LORAN C/D RECEIVERS

| | AN/ARN-92 | AN/ARN-85 | AN/PSN-2 | TDL-101 |
|---|---|---|---|---|
| WEIGHT (POUNDS) | 48 | 47 | 12.7 | 5 1/2 |
| POWER (WATTS) | 150 EST | 150 EST | 18 | 25 |
| VOLUME (CU. IN.) | 1292 | 1597 | 540 | 129 |
| OPERATION | AUTO | AUTO | MANUAL | AUTO |
| WARM UP (MIN) | 15 | 15 | NEG | NEG |
| SEARCH TIME | 180 (SEC) | 180 (SEC) | 180 (SEC) | 3 (SEC) |
| SETTLE TIME | 10 (MIN) | 10 (MIN) | 5 (EST) (MIN) | 3 (MIN) |
| TOTAL TIME | 28 (MIN) | 28 (MIN) | 8 (EST) (MIN) | 3 (MIN) |
| VEL. AID REQ'D | YES | YES | NO | NO |

T57058

Figure 7




# COMPLETE LORAN C/D RECEIVER

Figure 8

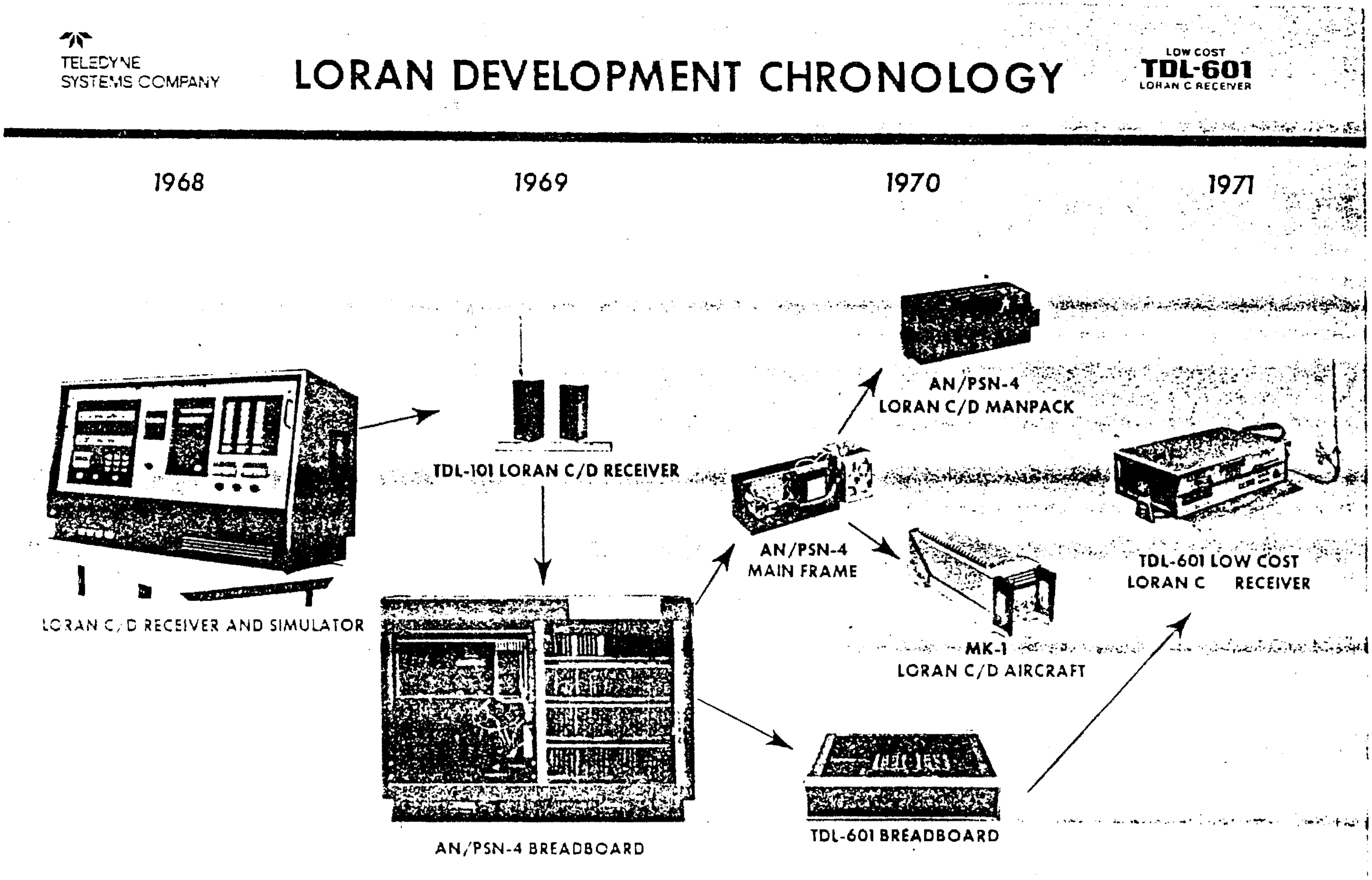
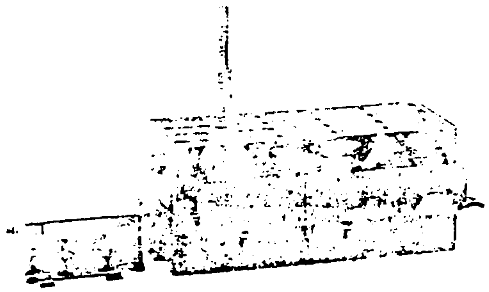
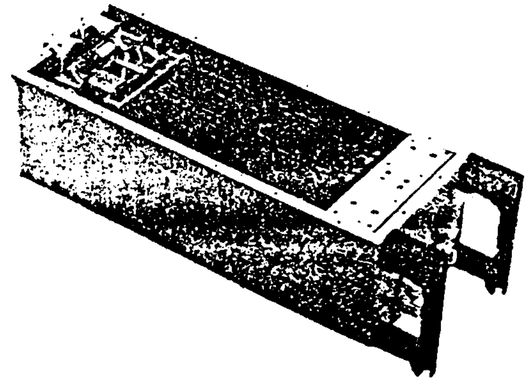

TELEDYNE
SYSTEMS COMPANY
LORAN DEVELOPMENT CHRONOLOGY
LOW COST
TDL-601
LORAN C RECEIVER
1968
1969
1970
1971
LORAN C/D RECEIVER AND SIMULATOR
TDL-101 LORAN C/D RECEIVER
AN/PSN-4 BREADBOARD
AN/PSN-4
MAIN FRAME
AN/PSN-4
LORAN C/D MANPACK
MK-1
LORAN C/D AIRCRAFT
TDL-601 BREADBOARD
TDL-601 LOW COST
LORAN C RECEIVER

Figure 9

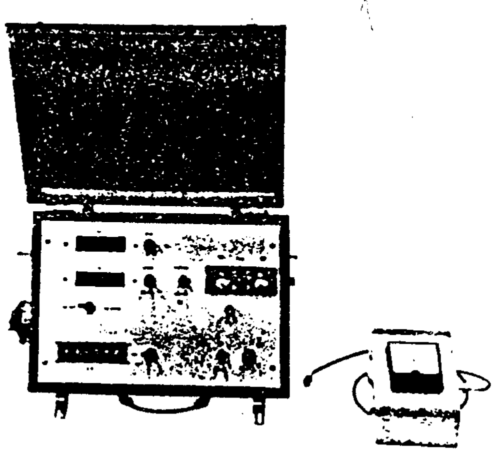


AN/PSN–4 LORAN C/D
POSITION LOCATOR

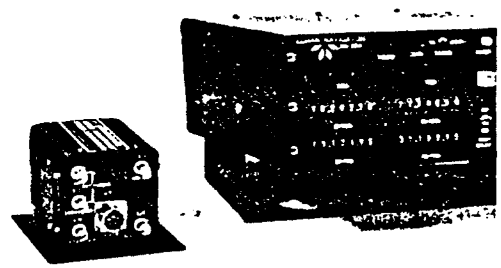


MKI LORAN C/D RECIEVER

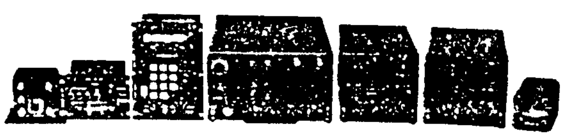
L

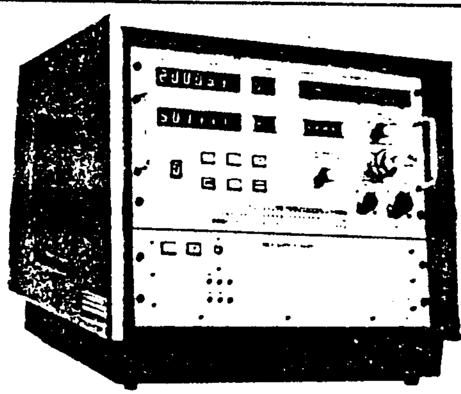


LORAN C/D LINE OF POSITION STEERING UNIT



TDL–301 LORAN C/D STEERIN





LORAN AIRBORNE MODULAR SYSTEM

applications are opening up. Many new applications (See Figure 11) are practical because of the improved performance, smaller size and lower cost of second generation LORAN C Receivers. Teledyne's current receiver has been used in a variety of configurations for many applications (See Figure 12). Rather than dwell on this list, I thought it would be more interesting to present a graphic story of actual real world situations where Teledyne's LORAN C Receivers have been used. Time doesn't permit a complete account but this is a fairly representative cross section. These growing applications have a snowballing effect. They stimulate a demand for expanded and improved LORAN C coverage and as coverage is expanded and improved, the applications will increase thus creating new and broader coverage demands.

## PROBLEMS

The biggest single problem facing LORAN C is the lack of coverage in many areas. This will be alleviated if the DOT National Plan is adopted, but we really need worldwide support. Unfortunately, this is threatened by the Defense Navigation Satellite System advocates who are struggling to get their program off the ground. Since they have little in the way of factual data to go on, they are somewhat uninhibited about their claims. For example, it should be obvious that a DNSS receiver is more complex and costly than a LORAN C receiver but somehow this fact has been obscured.

Lest anyone doubt the complexity of a DNSS receiver, recall the computer sizing requirement of 40,000 words stated in the ARN-101 RFP for DNSS provisions. I think we all accept the inevitability of the DNSS; however, it should proceed at a pace that can be economically justified and not arbitrarily launched just because it has a glamorous image.

Now to get to the problems that we can do something about. One is to standardize on the definitions of the important LORAN C parameters. Each procurement agency has its own definitions for signal, noise and noise bandwidths, input conditions, and rules for statistical treatment of measurements. Also, in today's laboratory environment, it is almost impossible to really check the relative merits of two different receivers, although if the same testing procedures are used, some valid conclusions can be drawn. However it is quite possible, using today's laboratory test methods, to have one receiver look very good in the lab and another look relatively poor and yet in the real world the exact opposite could be true. Since the major customers for LORAN C are still U.S. Government agencies, it would seem in everyone's best interest for them to get together on a set of standard definitions and realistic test conditions.

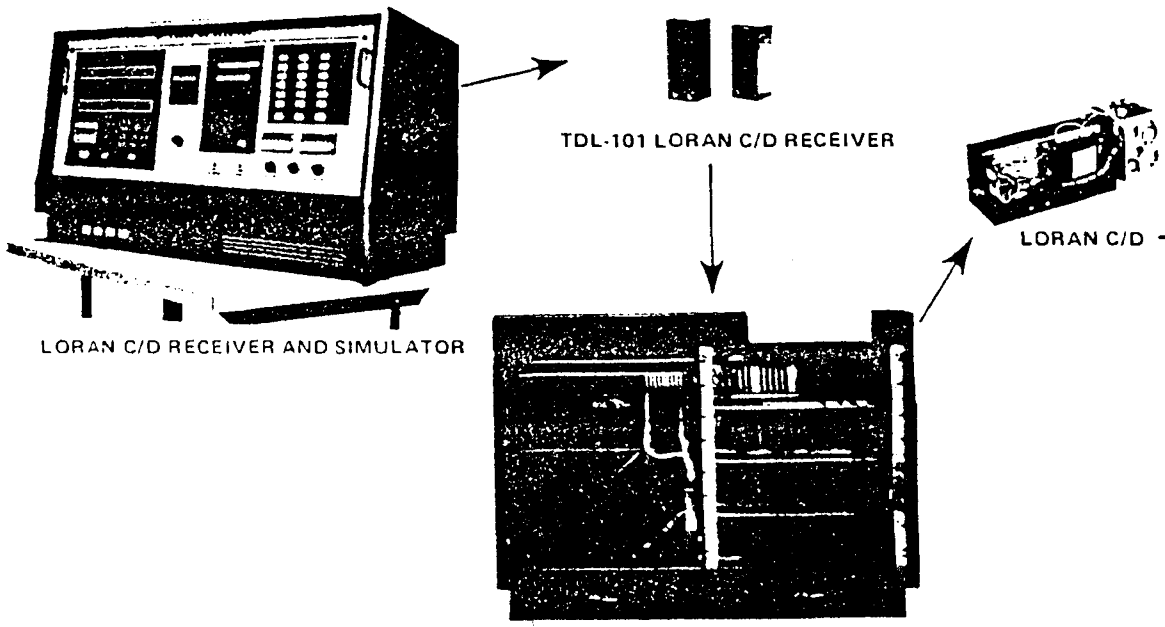
Another problem which has seriously detracted from LORAN C's reputation is the market in pseudo-LORAN C Receivers. These are very low cost receivers which are advertised and sold in the thousands as LORAN C, but in reality they come nowhere near processing the complete LORAN C signal. They are little more than dedicated oscilloscopes. Generally, these pseudo-LORAN C receivers track only the envelope. The effect is to pervert LORAN C into a LORAN A type system. Since LORAN A is designed for envelope tracking and LORAN C is not, LORAN C is made to

# LORAN APPLICATIONS

- HELICOPTER/VTOL
- HIGH PERFORMANCE & TRANSPORT AIRCRAFT
- DRONES (LAUNCH, GUIDANCE, RECOVERY)
- VEHICULAR
- PLATOON LOCATOR (MANPACK)
- FORWARD OBSERVER
- ARTILLERY DIRECTED FIRE
- DOWNED AIRMAN LOCATOR
- COMMUNICATIONS
- COVERT MARKER REFERENCE
- SEARCH & RESCUE
- RECONNAISANCE & SURVEILLANCE
- SAM SITE LOCATION
- MISSILE GUIDANCE
- WEAPON DELIVERY
- INTEGRATED NAVIGATION SYSTEMS
- UNIVERSAL TIME REFERENCE
- RE-ENTRY GUIDANCE & RECOVERY
- SHIPS NAVIGATION

Figure 11

# APPLICATIONS OF




LORAN C/D
MAINFRAME APPLICATIONS

- AN/PSN-4 LORAN MANPACK
- MK-1 LORAN AIRCRAFT
- AIRBORNE POSITION LOCATOR
- LORAN AIRBORNE MODULAR SYSTEM
- LORAN INTERIM NAV SYSTEM
- LORAN DRONE UPDATE NAV RECEIVER
- LORAN AIRBORNE NAVIGATION SYSTEM
- AERIAL SCOUT LORAN NAV SYSTEM

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TDL-601 LOW COST LORAN RECEIVER

AUTOMATIC VEHICLE MONITOR SYSTEM

T81338

Figure 12

appear less accurate than LORAN A. Another type of pseudo-LORAN C Receiver on the market goes one step beyond envelope tracking and cycle tracks, but only on one pulse instead of all eight pulses. The resulting power loss seriously degrades LORAN C system performance. These pseudo-LORAN C Receivers have biased many potential LORAN C customers against LORAN C. In face, some honestly believe that LORAN A is more accurate than LORAN C. We cannot stop anyone from selling a receiver, but it only seems fair that the product be advertised for what it truly is and not misrepresented as a bona fide LORAN C Receiver, which it certainly is not. I think the U.S. Coast Guard should take a stronger stand on this because the LORAN C System and the Coast Guard are suffering unfair criticism.

## TRENDS

The mechanism for new and expanded military applications is already in motion. The current AF and Army development programs will lead to LORAN C Systems for AF Tactical, Transport and Drone Aircraft and for Army Aircraft, Ground Vehicles and Personnel and possibly ships. LORAN C appears to be a logical choice for RPV's. It may also prove valuable for missile and bomb guidance and for space shuttle positioning. The Navy's applications will also increase as the coverage is expanded. And as search and rescue methods become more refined, LORAN C will likely play an important role. The recent tragic disappearance in Alaska of Congressman Hale Boggs might have been averted if LORAN C had been available aboard his aircraft. Also, the very high cost of the search would have been eliminated.

During the next decade there will be rapid growth in LORAN C coverage and in applications. This will spur greater competition to exploit the state-of-the-art in both hardware and software, and to bring the costs down further. New LORAN C receiver designs will move more in the direction of RF front ends with micro-programmed processors with MOS circuitry and semiconductor memories. In some designs, the RF front end will probably have additional capabilities, such as Omega or other VLF, and eventually satellites. The software improvements will allow operations on more than one GRI simultaneously and allow mixing LORAN stations (or other navigation transmitter stations) in any combination. Best signal strength and geometry will be the only criteria and it will not be necessary to receive a master transmission. More will be learned about LORAN C skywave so that the useful range will be extended. The accurate periodicity of the LORAN C signals will be put into more widespread use as a timing reference and on-board clocks will be synchronized to the transmitter clock by software techniques such as used in direct ranging LORAN. These software improvements will increase the utility of LORAN C. When combined with the planned expansion of the LORAN C network in the U.S. and the shutdown schedule for LORAN A, it is easy to understand the interest now displayed in LORAN C by airlines, shipping companies and fishing fleets. Another market that will open up as the cost of receivers continues to plunge is in the broad field of Automatic Vehicle Monitoring. This could easily lead to volume requirements in the hundreds of thousands. This will be a catalyst for further expansion in LORAN C coverage and now that convenient portable LORAN C mini-chain transmitters are available, it is practical to install LORAN C anywhere in the world.

## CONCLUSION

The spurt of new developments and burgeoning applications signal the beginning of the rapid growth in LORAN C popularity. The second generation of LORAN C receivers has already begun to make its presence felt and faces an interesting and challenging future: Its performance has stimulated the imagination of military and civil planners; healthy technical controversies simmer relating to design optimization; and, understandably, it is experiencing growing pains in terms of efforts to standardize on definitions and to write realistic performance specifications that can be measured in a laboratory environment. That the future of LORAN C is very bright is confirmed by your attendance here today.