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REPORT ON A PRELIMINARY INVESTIGATION OF FACTORS INFLUENCING THE DESIGN OF A LIGHTWEIGHT PARATROOP BEACON

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INTRODUCTION

This report will discuss briefly the findings of a two months' study of the technical factors influencing the design of an ultra-portable paratroop beacon of special characteristics.

The problem of designing of a paratroop beacon to meet the tentative specifications resolves itself into the following considerations:

1. Choice of operating frequencies.
    a. Operation with existing radars.
    b. Availability of a suitable low-drain transmitting tube.
    c. Suitability with respect to position resolution.
    d. Security from known enemy radars.
    e. Rigging of antennas by inexperienced personnel.
2. Choice of power supply.
    a. Suitability for long life in the expected climatic conditions.
    b. Multi-input type.
    c. Circuit arrangements to conserve power.
3. Choice of reliable design for minimum power drain.
    a. General system
    b. Receiver
    c. Decoder
    d. Switching circuits
    e. Coder
    f. Transmitter
    g. Antenna
    h. Test equipment
4. Packaging

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a.

a. Security

b. Ease of handling

c. Dropability

d. Protection from weather

The findings reported here are subject to revision due to the fact that an investigation of other possibly system and component designs will continue during the development of the first models.

The remainder of the report consists of Section I, Recommendations for First Model Design; Section II, Discussion of Factors Influencing the Recommendations; and Section III, Conclusions.

SECTION I

RECOMMENDATIONS FOR FIRST MODEL DESIGN

The following is a brief list of recommendation design features for a first model beacon.

1. Operating frequencies - X-band for both receiver and transmitter.

2. Power supply - Separate unit construction is recommended to allow for various weights of batteries under various weather conditions. Such construction will also allow use of available a-c power. LeClanché low-temperature batteries are temporarily recommended until low-temperature tests can be performed on the Yardney "Silvercel."

3. Reliable design for minimum power drain.

    a. Receiver - A crystal-video receiver using five low-drain subminiature pentodes and a biased crystal detector is recommended.

    b. Decoder - a Two-tube pulse-repetition-frequency decoder is recommended. The same tube types as in the video amplifier should be used.

    c. Switching circuits - A one-tube relay circuit for actuating the transmitter section is recommended. The same tube type as used in video amplifier is recommended.

    d. Coder - It is recommended that there be no coding of the reply.

e.

e. Transmitter - the QK299 is recommended as the transmitting oscillator. The 2D21 is temporarily recommended as the modulator switch tube pending the outcome of tests on the subminiature 2D29.

f. Antenna - It is recommended that an existing omnidirectional beacon antenna be used.

g. Test Equipment - It is recommended that a resonant buzzer test-signal generator be used.

4. Packaging

a. The use of camouflage should be considered, but no recommendation can be made. Means for self-destruction should be included.

b. It is recommended that the package consist of two cases, the transmitter receiver case and the power supply case. Both should be designed to be handled simultaneously by one man.

c. It is recommended that to minimize bulk and weight, removable dropping containers be used when needed.

d. Hermetic sealing of the entire transmitter-receiver case is recommended.

SECTION II
DISCUSSION OF FACTORS INFLUENCING THE RECOMMENDATIONS

1. Choice of Operating Frequencies

a. The operating frequencies of both the receiver and the transmitter may be chosen freely for optimum beacon operation. However, it is desirable for the first model to be designed to operate with existing airborne bombing and navigation radars with as few modifications to the radars as possible. This consideration makes X-band the logical choice for both the receiver and the transmitter.

Very little increase in sensitivity can be gained by operating a crystal-video receiver at lower frequency. It is, therefore, not likely that further study will affect the choice of receiver frequency except insofar as overall system choice may dictate.

b. The choice of transmitting frequency is mainly a matter of finding a low-drain oscillator tube of sufficient power regardless of operating frequency. This is true because, for line-of-sight operation

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with a fixed antenna intercept area, the power required for a given range is independent of frequency except for atmospheric absorption.

Such a consideration indicates that a low frequency is the logical choice for transmission because of the higher plate efficiencies obtainable from low-frequency oscillators. For the type of operation contemplated, however, filament power is the primary consideration. For a reliable range of 100 miles using antennas of reasonable size, a peak power of the order of 100 watts is required. Of the tubes capable of this order of peak power in the 100 to 10,000 Mc range, few require less heater power than 0.6 ampere at 6.3 volts.

This is the filament power required by the recently developed QK299, tunable X-band magnetron. This tube is capable of 300 to 1000 watts peak power at 30 to 45 percent plate efficiency. No other microwave oscillators were found to compare favorably with these characteristics, although a number of low-frequency tubes are available that require about as little as one-fifth as much filament power. It is believed that the desirability of using X-band in the first model is sufficient to outweigh the slightly longer battery life that would be available if a low-frequency transmitter were used.

c. One of the important systems considerations that makes X-band desirable for transmission is the high resolution obtainable in azimuth with available high-gain X-band radar antennas.

To obtain the available resolution, it is necessary to maintain the gain of the X-band receiver at such a level that minor-lobe response is not evident. Two alternatives for accomplishing this result are available. Automatic gain control can be used in the beacon receiver, or either manual gain control or automatic gain control can be used in the radar receiver. In either case it is necessary that the gain-controlled receiver be at X-band or at a frequency at which the required directivity can be obtained.

Due to the added complexity and hence power-drain, it is undesirable to add automatic gain control to the beacon receiver. Therefore, it is desirable to use an X-band beacon transmitter.

d. Added security for the beacon can be obtained by operation of its receiver at frequencies outside the much-used radar and beacon bands. Such operation would require the use of a specially designed interrogating radar transmitter of power comparable with that of the usual X-band radars. Such a design is probably not feasible at microwaves where new components would have to be designed.

Cross-band operation would also add to the security of the beacon. It is believed, however, that prf coding will provide sufficient security without the necessity for cross-band operation.

e.

e. One of the more difficult operational problems is the installation of the antenna in a satisfactory location. It is probably true that, the higher the operating frequency is, the more difficult it will be for untrained personnel to install the antenna satisfactorily.

From this consideration low-frequencies would be more desirable than microwave frequencies. It is intended that this aspect of system design will be studied further.

2. Choice of Power Supply

a. The primary consideration in the choice of batteries is their suitability for long life at low drain under the expected climatic conditions. There are two types of batteries that are suitable for this application from the standpoint of watt-hours-per-pound.

The LeClanché low-temperature dry cell exhibits a watt-hours-per-pound characteristic which increases with decreasing current drain. A ten-to-one reduction in current drain approximately doubles the watt-hours-per-pound capacity. At room temperature the LeClanché cell has a capacity of between 50 and 100 watt-hours per pound for the current drains contemplated for the beacon. The capacity is reduced almost linearly to a value of about 15 percent at -60°F. Figure 1 shows LeClanché battery weight required as a function of temperature.

The room temperature capacity of the Yardney "Silvercel" actually exceeds that of the LeClanché dry cell and in addition can be recharged a large number of times.

The low-temperature characteristics are still not known definitely. Conflicting unofficial reports have been received. One report indicated that satisfactory operation could be obtained at -20°F with derating to only 50 percent of room-temperature capacity. Another report indicated that drastic reduction to less than 10 percent of room-temperature capacity occurs at 0°F and below. This discrepancy will be cleared up by cold-chamber tests.

If the rechargeable feature is found essential, the Yardney "Silvercel" is the logical choice provided the cold-chamber tests prove it to be satisfactory. However, if the "Silvercel" proves unsatisfactory at low temperatures, the low-temperature, lead-acid cell is the next best choice. Its derating at low temperatures is much less than that for the LeClanché cell, and its capacity approaches that of the LeClanché cell at -60°F.

The other cell types considered were the nickel-cadmium, the zinc-mercury, and the non-rechargeable silver cell. These types are best suited for short-life, high-rate discharge and exhibit poor low-temperature

characteristics.

characteristics. There are also several "single-shot" short-life batteries available, but their characteristics were not considered applicable to this problem.

b. The possibility of providing multiple inputs was considered, but it is believed that best use can be made of the allowed weight and volume by concentrating on one efficient type of power source.

A logical alternative to the multiple input power supply is the use of a separate replaceable power supply package. A number of different power supplies could then be designed for particular weather conditions and locations.

c. Several unusual techniques for reducing the duty ratio of the batteries were considered.

The high power requirements of suitable modulator and transmitter tubes make it essential that they draw current only during an active transmission. Relay circuits must be provided to operate from a signal accepted by the decoder. The operation should be such that modulator and transmitter filaments will be turned on by the first accepted pulse packet, plate voltage will be applied 10 to 15 seconds later, and both will be held on for as suitable time after the last interrogation.

The possibility of using sunlight switching, clockwork switching, and electronic switching to reduce the "on" period of the beacon by 50 percent or more was considered.

Sunlight switching is obviously useful only when operation will be expected only at night or only in the daytime. It is believed that such a restriction of operating time more than balances the increased life expectancy of the beacon. It is, therefore, not recommended.

Clockworks of satisfactory characteristics have not been found for study.

Electronic switching could possibly be used for switching at a recurrence period of several seconds. However, any of the schemes for reducing the battery duty ratio at the same time reduce the probability of receiving a correct interrogation. It is therefore believed that only the "on-off" relay for the transmitter and modulator should be incorporated in a design.

3. Choice of a Reliable Design for Minimum Power Drain

a. The requirements of reliable, long-life operation and low power drain are antagonistic. However, it has been found that an X-band

beacon

beacon can be built to weight approximately 44 pounds and have a life of 3 weeks to 6 months depending upon temperature conditions and the total length of interrogation time.

The suggested beacon design consists of an X-band crystal-video receiver followed by a decoder and a transmitter "on-off" switching circuit which turns on the modulator and transmitter tube after receiving an interrogation.

b. The crystal-video, the super-regenerative, and the superheterodyne circuits were considered for the receiver design.

For X-band the superregenerative receiver cannot be used because of the lack of a suitable tube.

A superheterodyne requires the use of a high-drain local-oscillator tube and is hence unsuitable. Besides these short-comings both the superregenerative and the superheterodyne radiate r-f energy which would reveal the location of the beacon.

The crystal-video receiver, although of marginal sensitivity, is by far more economical of battery power than the superheterodyne.

To eliminate the filament drain of the video amplifier, transister amplifiers were considered; however, their inherent non-uniformity and instability, especially with respect to temperature variations, make their use inadvisable. Suitable low-drain subminiature pentodes are available for the video amplifier.

A recent investigation has shown that the sensitivity of a crystal-video receiver, can be increased from -45 dbm to about -60 dbm for a tangential signal by the use of 10 microamperes of forward bias. The use of such bias also stabilizes the crystal impedance and current sensitivity factor against variations due to temperature changes. The resistance of a typical unbiased crystal varies from about 3000 ohms at + 150°F to about 400,000 ohms at -60°F. The resistance of the same crystal varies from about 2500 ohms to about 9000 ohms when biased with a constant current of 10 microamperes. Current sensitivity factor for the unbiased crystal changes about 3 or 4 to 1, but stays vitually constant with constant-current bias. A constant-voltage bias allows approximately the same order of variation of characteristics as zero bias. For unattended operation at peak performance, it is essential that the impedance (and hence noise voltage) and current sensitivity be as nearly constant as possible.

The

The reliable range on interrogation can be calculated from the range equation

$$R_{Rel} = \frac{\lambda}{4\pi} \sqrt{G_R G_T} \times \sqrt{\frac{P_T}{P_R}}$$

where

R_{Rel} = reliable range in the same units as the wavelength

λ = wavelength

G_R = receiver antenna gain (at 3 db points)

G_T = transmitter antenna gain (at 3 db points)

P_T = transmitted power

P_R = receiver tangential signal power

Typical values for a low-powered X-band airborne radar would be

$\lambda = 3.2 \times 10^{-2}$ meter $= 2 \times 10^{-5}$ mile

$G_R = 0.5 \times 3.0 = 1.5$

$G_T = 0.5 \times 10^3$

$P_T = 8 \times 10^3$ watts

$P_R = 4.0 \times 10^{-9}$ watts (allowing 6 db safety factor)

giving

$R_{Rel} = 61$ miles

Maximum range at antenna gain peaks and optimum receiver performance would be

$$R_{Max} = 4 \times 61 = 244 \text{ miles}$$

For interrogation on 2.2 microsecond pulses a band-width of 240 kilocycles per stage is sufficient to give pulse reproduction which reaches about 30 percent peak amplitude. The choice of such a narrow bandwidth is necessary because of the low gain-bandwidth product of low-drain subminiature pentodes. With this bandwidth a gain of about 10^6 is required to bring a tangential signal to the 1 volt level. Five subminiature CK544DX tubes are sufficient for this gain and bandwidth at a drain per tube of 13 milliwatts filament power and 6 milliwatts plate and screen power. Total video amplifier power drain should then be about 0.1 watt.

The

The added complication of screen bypassing when using pentodes is offset by the fact that no suitable low-drain triode is available. The subminiature capacitor art has reached such a state that this problem is no longer a severe design limitation.

c. The decoder security requirement is such that the life expectancy of the beacon should not be seriously impaired by the use of a large number of tubes in a multiple-pulse circuit, and at the same time the probability of accidental triggering by known models of existing radars should be very small. Another consideration in decoder design is the desirability of requiring as little modification of the airborne radar as possible.

A prf decoder using an LC ringing circuit operated by a pentode, the pulse input of which is amplitude-limited, was the most promising type investigated. Such a decoder can be designed to have a reasonably fast response and narrow bandwidth simultaneously because of the bandwidth-narrowing effect derived from the amplitude-limited input. Two CK544DX pentodes are sufficient for the decoder. The decoder power drain should then be 0.04 watt.

It should be possible to make such a decoder to reject any prf differing by more than ± 0.7 percent from the correct frequency. The radar prf can be accurately controlled to a frequency chosen to be as far removed from known radar repetition frequencies as possible. Probably 330 to 360 cps is a useful range to which most 400 pps radars could be easily modified with a slight reduction in transmitted energy.

It is believed that high traffic capacity will not be a problem of the decoder for this beacon.

d. After the decoder has accepted an interrogation, it is necessary that the modulator and transmitter filaments be turned on and that there be a delay of at least 10 seconds before plate power is turned on. It is also desirable to have a delay following the last interrogation to prevent the occurrence of dead times due to fades.

Comparison of mechanical and electronic delay switching schemes showed the electronic method to be the more economical of power and sufficiently reliable. A single CK544DX tube using 0.02 watt is sufficient for both switching operations.

A large number of contacts is required in this operation because of the fact that the 30 or 45 volt batteries normally paralleled for receiver operation must be placed in series to give about 450 volts for transmitter operation. A large number of 6-milliwatt SPDT switches can perform such an operation at less power drain than fewer multicontact switches. Approximately 20 such switches will be required.

e.

e. It is believed that identification coding will not be required in this application and, therefore, no coder should be required.

If, however, it is decided to use coding, there is available a simple scheme of ~~multiple-~~pulse coding that requires no more active circuits than the non-coded reply. The scheme consists of using a pulse-forming line which generates a video modulating pulse with 100-percent "ringing" modulation superimposed. The "ringing" frequency can be set for each beacon to give a predetermined number of equally-spaced pulses per reply.

Coding requiring the use of several additional tubes to generate the codes should not be used because of the added battery drain.

f. The choice of a transmitting tube was eased by the recent development of a low-drain X-band magnetron, the QK299. Its power capabilities range from 300 watts at 30-percent efficiency at 2500 volts to 1000 watts at 45 percent efficiency at 3500 volts. Its filament power drain is 3.8 watts and average plate power drain about 0.5 to 1.0 watt. There are no other known X-band tubes of comparable characteristics.

However, for frequencies from 1000 to 3000 megacycles the RCA pencil triode and the GE L29 ceramic triode are capable of about 100 watts peak at considerably less power drain.

As a modulator the 2D21 miniature thyratron has satisfactory characteristics. Its heater power is 3.8 watts and its plate power loss should be about 5 percent of the modulating pulse power.

The subminiature 2D29 is being studied as a possible short-life substitute for the 2D21. The tube is designed for use in long-range missiles and is, therefore, not a long-life type. If its life promises to be greater than 100 hours, it should be used. Its filament power is only 0.13 watt.

The reliable reply range available using the QK299 can be calculated from the expression

$$R_{Rel} = \frac{\lambda}{4\pi} \sqrt{G_T G_R} \sqrt{\frac{P_T}{P_R}} \sqrt{L_S \times L_O} \qquad (2)$$

where

L_S = scanning loss

L_O = loss due to off-band operation

Other symbols same as in (1)

Using

Using $P_T = 300$ watts, $P_R = 4 \times 8 \times 10^{-13}$ watts (allowing 6 db safety factor), $L_S = \sqrt{\frac{6}{360}}$ (for 6-degree beamwidth), and $L_0 = 1.0$ (for radar-band operation) the reliable reply range is

$$R_{Rel} = 152 \text{ miles.}$$

There is a margin of 8 db in power to allow for slight off-band reception in the airborne receiver.

The maximum "searchlight" range using no safety factors would be

$$R_{Max} = 1700 \text{ miles.}$$

g. There are X-band antenna designs available that are suitable for this application. One in particular consists of an omnidirectional horizontally polarized triple tripole antenna with a gain of 3. Single-wire transmission lines are being studied in an effort to facilitate remote placement of the antenna.

Directional antennas obviously should be avoided unless the interrogation bearing is known. This is an unlikely situation.

The proper placement of the antenna will be one of the most difficult operational tasks. To obtain omnidirectional characteristics there must be no shadowing objects such as trees, hills, buildings, etc. The acuteness of this problem strongly suggests that an operating frequency below the U.H.F. range be used. In such a case it would be necessary to use direction-finding techniques to obtain azimuth information. However, considerably less care could be exercised in the placement of the antenna at these frequencies than is required at X-band.

If a parallel design were to be considered because of antenna difficulties, the operating frequency should probably be between 2 and 20 megacycles. Such a system would require complete development of an interrogator including its direction-finding components as well as the beacon. A large saving in transmitter power consumption could be obtained at these frequencies, but receiver power would not be changed.

h. For testing, only the simplest of test gear were considered. Since the decoding is done on the prf, a buzzer-type noise generator resonant at the proper prf should give sufficient signal of proper characteristics to actuate the beacon.

4. Packaging

a. One of the foremost problems of packaging is one of security. Camouflage and self-destruction techniques should be used, but no recommendations can be made. The various phases of this aspect will be studied further.

b.