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A SYSTEM CONCEPT FOR MAIN-BEAM COLLECTION

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I. BACKGROUND

The reconnaissance mission of searching for new radar signals (now called new weapons systems search) has traditionally been accomplished by collection systems which intercept minor-lobe radiation from radar emitters. Examples include the 770 program, and most of the P-11 program; the noteable exception being the POPPY system. Within the overhead program, the general belief has existed that intercept of radar main-beams is a venture with low probability of success. This long accepted assumption should be seriously challenged by the recent success of the existing main-beam collection program in obtaining first intercept on most of the ABM family of emitters. The success of the POPPY system has demonstrated that main-beam intercept does indeed give high probability of intercept of new emitters in the R & D testing phase.

The success of the POPPY system is no doubt in part due to the ease of processing of main-beam collected data as contrasted to the difficulties inherent in deinterleaving high density data collected from minor lobe intercept systems. This, again, points up the necessity of having a compatible collection-processing system which must be treated as an overall system operation in order to maximize the flow of intelligence product output.

The following proposal suggests implementation of a new main-beam intercept payload series with a substantially expanded signal parameter measurement capability to either supplement or replace the present low altitude weapons systems search program. This concept can provide all the basic radar signal parameter measurements, single pulse direction of arrival, instantaneous frequency, PRF, pulse duration, precision TOA, antenna scan patterns, and ERP, which are required to define emitters, all in a single payload. At the same time, it retains the simplicity of processing POPPY-like main-beam collected data of low to moderate density while avoiding both the high density de-interleaving and the data merging problems inherent in 770 and P-11 pencil beam minor lobe intercept systems.

This proposal also provides a capability for handling both frequency jump and modulated PRF emitters which may be encountered in future environments.

II. PREMISE

This collection concept is based on the following premise: that radar main-beam intercept has sufficiently high probability of success as to be acceptable for the search function, and further that a coarse emitter location capability is acceptable in the search function. A refinement is, however, proposed which will provide high accuracy emitter location if desired.

III. PROPOSED FUNCTIONS

The system will make the following kinds of measurements on each arriving main-beam pulse.

(a) Direction of arrival in azimuth

(b) Direction of arrival in elevation

(c) Frequency

(d) Pulse repetition interval (on a single antenna?)

(e) Pulse duration

(f) Pulse amplitude

Optional measurements which may be made with this system concept include:

(a) Polarization (complete polarization elipse)

(b) Frequency modulation on pulse

  (1) A flag indication of FMOP, or

  (2) Predetection recording of a compressed bandwidth version of the pulse

(c) Precision time of arrival for high accuracy emitter location

(d) CW signal detection (main-beam)

IV. PLATFORM CONSIDERATIONS

The platform will need to be stabilized in some fashion in order to determine direction of arrival of radar main-beams on a monopulse basis. An earth oriented stabilization, obtained either by gravity gradient, or gas or magnetic stabilization would be ideal if vehicle yaw can be accurately sensed and indicated. The spin stabilized vehicle avoids this problem by use of the horizon sensor at a slight cost in computational complexity to calculate the instantaneous rotation angle of the vehicle.

The vehicle will need to be of sufficient size to carry payloads (receivers and collection antennas) totaling approximately 100 lbs.

V. MEASUREMENT TECHNIQUES

A brief outline follows which illustrates the technological approaches presently available to satisfy the measurement requirements previously outlined. These in general make use of monopulse measurements of all signal parameters.

A. Direction Finding

Monopulse measurements of direction of arrival in azimuth and elevation will provide DF cuts on horizon-based emitters and a series of cuts will converge to a specific location. Emitters underneath the ground track, with a high elevation angle radiation capability, can be located on a single pulse basis. Three techniques appear attractive for making monopulse direction of arrival measurements:

(1) Multilobe amplitude comparison monopulse from a set of wide solid angle antenna pattern lobes pointing in all directions or,

(2) Phase comparison monopulse from a minimum of three antennas or,

(3) Differential time of arrival measurements at three separated antennas.

If the direction of arrival information were coded as binary bits, approximately 15 bits would be needed in the case of the amplitude monopulse proposal to identify the three strongest signal antennas and specify the ratio of amplitudes in these antennas to a digital quantization resolution of 1 dB.

B. Frequency

For a main-beam collector, frequency measurements can be made on a pulse-by-pulse basis with a broadband delay-line frequency discriminator which can cover up to an octave or more of microwave band, and provide frequency measurements accurate to within a few percent of the bandwidth covered. The microscan concept of matched filter receivers investigated at Stanford may also have application to this kind of measurement although it is perhaps unnecessarily complex for this function.

A capability should also be provided for main-beam intercept of high power CW radar signals, since little collection capability has previously been provided in this area. This can easily be done by use of either a swept YIG filter or an electronically scanned superhet receiver.

The frequency measurement information including indication of CW type transmission can be encoded in 9 bits of a digital word.

C. Pulse Repetition Interval

It is proposed that a digital word be written for each main-beam pulse impinging upon the vehicle. This word would start at the next zero crossing of the timing tone, thus quantizing pulse time of arrival to the nearest cycle of the reference tone. If greater precision in time of arrival is necessary for PRI doppler emitter location, a measurement can be made of the time from the arrival of the pulse to the beginning of the digital word representing that pulse.

If considered necessary, 6 bits of precision TOA could be coded into the digital word; the word rate will be the basic signal PRF.

D. Pulse Duration

High accuracy pulse duration measurement circuits are proposed similar to those used in the SAMPAN series receivers. With the clean (multipath-free) main-beam pulses received, repeatable accurate measurements should be consistently generated with an absolute accuracy in the vicinity of 0.05 μsec.

Six to 8 bits of pulsewidth information should be adequate.

E. Pulse Amplitude

A multiplicity of overlapping antenna patterns should permit measurement of the peak power of received pulses to rather high accuracy in order to obtain radar ERP and beamwidth data. With care in circuit design, it should be possible to preserve received power level to an accuracy of 1 dB over a 40 dB dynamic range.

Six bits of information would provide a 1 dB quantizing accuracy.

F. Polarization

If desired, in the microwave bands a polarization measurement could be made which would show the complete polarization elipse including axial ratio, orientation of major axis, and sense of polarization. The microwave polarimeter technique* explored at Stanford

* "An Instantaneous Microwave Polarimeter", M. Crane, et.al, Stanford Electronics Laboratories, May 1964. TR No. 1821-2

could be applied here. The technique in general would not be useful in the VHF range because of the large amount of polarization rotation inherent in propagation through the ionosphere.

G. Frequency Modulation on Pulse Indication

Since main-beam intercepts are generally free of multipath or other distorting influences, an ideal opportunity exists for detecting spread spectrum modulation on radar pulses, with FMOP detection circuits. Although it is difficult to design such circuits to operate over wide ranges of unknown parameters with low false alarm rates, it may be worth exploring techniques which can provide a flag indication of this type of transmission. A further concept which may be a bit far out, but perhaps worthy of consideration, is the use of a SLEW-TO concept predetection recording subsystem with bandwidth compression such as is being proposed for the microwave TIVOLI. If one accepts the initial premise on which this main-beam collection concept is based, then perhaps the fine grain technical intelligence objectives can be satisfied on a similar basis, i.e., within this kind of main-beam collection payload.

VI. DATA FORMAT

The proposed basic format is based on the writing of a digital word for each pulse received at the vehicle. Between 40 and 50 bits of information per word would be required to preserve the measurements in the previous section, and the timing of the words would yield the PRF of the emitter. In addition to the digital word representation, an audio channel should be placed on a VCO to permit aural monitoring or scanning of tapes for signals of interest. This output would be similar to the present P-11 omni-video or POPPY video. The presence of CW energy should also be placed on a VCO for audible detection of CW emitters. This could perhaps be in the form of a klaxon sound while CW was present. Other information which would need to be recorded would be the horizon sensor data, vehicle clock, reference tone, and the vehicle and payload health and command status.

For main-beam collection, horizon-to-horizon intercept over the entire geographic area of interest is necessary. This can be provided by the 1 MHz tape recorder run at a 4 - 1 speed ratio, giving 2 each 250 KHz bandwidth tape tracks. One track can have a 250 KHz reference tone and handle the above digital bit rate at a maximum of 7,000 words per second, thus keeping up with a 7 KHz PRF without missing pulses. The other tape track can be used for the other VCO's and all other payload and vehicle data.

VII. DATA PROCESSING

This proposed system will be designed on the basis of an integrated payload-processing system, relying heavily on the successful POPPY processing system. The rather difficult merging of data presently required between the POPPY and P-11 main-beam receivers and the 770 and P-11 DF receivers in order to correlate antenna scan parameter intercepts with DF intercepts, will no longer be necessary with this proposed system. Main-beam DF gives inherently merged data. Furthermore, pulse trains can be deinterleaved on the basis of repetitive direction of arrival measurements, or repetitive frequency measurements, or both, thus simplifying the deinterleaving.

The frequency jump and modulated PRF radar collection requirements of the future can be handled by this system capability. The processing philosophy should be based on first sorting out the constant frequency, constant PRF emitters on the usual PRI deinterleaving basis, or by sorting on direction of arrival. After these emitters are extracted, the residue can be sorted on a constant frequency-constant direction of arrival basis to identify the modulated PRF emitters. The final step would then be to sort on repetitive direction of arrival of the remaining residue to define the frequency jump emitters.

The more complex radar antenna scan patterns will be sampled or mapped by this system through vehicle motion across the radar scan volume in a known fashion, thus permitting easy analysis of complex multi-dimensional antenna scan patterns.

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VIII. IMPLEMENTATION EXAMPLE

The C & X band ranges might be attractive for consideration as a first implementation of this concept, partially because of the difficulties apparently attendant in processing the present TRIPOS-SOUSEA data output. The main-beam collector could be implemented using amplitude monopulse for the coarse DF with a total of 6 spiral antennas, each with a beamwidth in the vicinity of 80°, mounted on the 4 sides and the top and bottom of a P-11 vehicle. At the beam crossover points fairly accurate direction of arrival measurements could be made with the measurements weighted in the computer in accordance with their individual accuracy. Frequency would be measured with a pair of broadband frequency discriminators covering the 4 - 8 and the 8 - 12 kMHz frequency range. A tunnel diode amplifier limiter would be used in front of the frequency discriminator. Swept YIG filters would provide

* Can be implemented only in a transpond mode; cannot be tape recorded in the vehicle.

a CW intercept capability, with a sensitivity somewhat higher than that of the pulse measuring receiver. A crystal detector with possible low-gain tunnel diode preamp would be used on each antenna, with a separate video amplifier for each channel. Amplitude comparison logic circuits would measure the ratio of amplitudes between channels and report in digital word form, the ratios of these various amplitudes for angle of arrival determination. Other measurements would be made in accordance with the suggestions of Sections V and VI above. For this particular payload, consideration should be given to the possible inclusion of FMOP indication or recording.

IX. CONCLUSIONS

The main-beam collection system as proposed, should provide all the data now presently being collected with minor lobe collection systems in a form which is easy to process and analyze. All of the measurements presently being collected by minor lobe and main-beam systems can now be collected in a single system in inherently merged form, such that all of the measurements, including scan characteristics and location of a given emitter, are easily correlated or associated. Both a coarse DF and a precision emitter location capability can be provided. The main-beam collection concept operates on clean multi-path free main-beams which provide a low to moderate data rate at the collection vehicle.

One question which has been raised concerns the behavior in a multi-beam radar environment. Since most multibeam emitters have beams on multiple frequencies oriented in slightly different directions, the receiver will generally be in the strongest portion of one beam at any given time, and by virtue of the small signal supression effect of the TDA limiter, give accurate measurements on that beam. As a function of time however, the vehicle will traverse various elevation and azimuth angles through the beam structure, thus permitting mapping of the beam structure including azimuth and elevation angle beamwidth and corresponding frequencies with good absolute power level precision. This feature provides a unique capability which does not now exist in any one system; furthermore, these radar parameters are often difficult to infer by correlation of measurements from different collection systems. This capability will be of particular value in analyzing future frequency diversity radar systems.

If this concept is of interest to the program, the next step will be additional study to define missions and their implementation on specific vehicles. Consideration will be given to obtaining maximum frequency band coverage as limited by the size, weight and power constraints of various vehicles.

X. ADDENDUM

As conceived, the system concept has been oriented towards implementation on a P-11 spin stabilized vehicle at an altitude of 274 nm with wideband tape recorder and wideband downlinks. This size vehicle (or a larger vehicle) is necessary, primarily because of the power and weight requirements commensurate with the required data storage and downlink bandwidth needs.

If in the interest of timeliness of reporting data, a transpond mode were also to be used, then a higher altitude, perhaps 500 nm for transpond coverage would be desirable. Use of the present POPPY vehicle and POPPY ground sites does not appear attractive for implementation of the entire concept however, because of bandwidth limitations on both ends of the downlink. However, a possible alternate solution would be to use the full concept as proposed with onboard tape recorders and S-band downlinks, together with a secondary VHF downlink of narrower bandwidth to provide realtime transponding to the POPPY ground sites. Operating at a reduced data rate, this VHF narrowband downlink system could provide TOA of each pulse together with perhaps just the frequency measurement bits which would be tailored to fit within the present ground site receiver bandwidths. This subsystem would provide realtime reported PRF, scan pattern, and frequency data to the sites to be analyzed on-station with the additional possibility [redacted]

[redacted] The tape recorded wideband data to be analyzed at a later time would provide the complete measurements to be analyzed in detail. [redacted]

It is suggested that this variation of the concept which combines some of the best features of both the POPPY and P-11 program may be useful as a single unified future low altitude collection system, at least for satisfying radar collection requirements.