~~TOP SECRET~~ [redacted]

BID NO. 95290

DECEMBER 3, 1959

A PRELIMINARY DRAFT
OF A
TECHNICAL PROPOSAL
FOR AN
L-BAND OMNIDIRECTIONAL
TRANSISTORIZED CRYSTAL-VIDEO
RADIO RECEIVING SYSTEM

HANDLE VIA
BYEMAN-~~TALENT-KEYHOLE~~
CONTROL SYSTEMS JOINTLY

PREPARED BY

~~TOP SECRET~~

DEFENSE ELECTRONICS LABORATORY
[redacted] LABORATORIES
FT. WAYNE, INDIANA

1 of 2

~~TOP SECRET~~

1.0 Introduction

This is an unso [redacted] d proposal written to describe an L-Band (500-1300 mcs) omnidirection [redacted] stal-video receiving system. ITT Laboratories, a research and development organization, does not normally operate on an "on-the-shelf" hardware type of procurement. However, due to the similarity of the proposed L-Band system and a previously developed S-Band system and the work done in the preparation of this proposal, the system is, for the most part, designed and ready for preliminary fabrication. It is the purpose of this proposal to demonstrate that ITT Laboratories has the engineering experience and know-how to complete the development of an L-Band receiving system.

2.0 Technical Requirements

The system requirement of the proposed equipment is to produce a tangential signal output across a 270-ohm load when the equipment, normally mounted in a 20 inch spherical housing, is illuminated by a pulsed r-f signal of 2.5×10^{-10} watts per cm^2 density. The performance is to be achieved throughout the frequency range of 500 to 1300 MCS, for all housing orientations and signal polarizations. The system requirements to achieve this performance are discussed in this section and the antennas, filter-detector units and amplifiers are discussed separately in later sections.

It is appropriate, before these components are discussed, to analyze the system sensitivity problem and determine the requirements it imposes on each of the components. It is convenient, for this analysis, to consider the power level in the r-f transmission line ahead of the crystal and the compatibility of the signal level received when the antenna system is exposed to the 2.5×10^{-10} watts per cm^2 field with that required to produce a tangential signal output.

Consider first the signal which would be received if it were possible to use a single, omni-directional, bi-polarized antenna with the system. A linearily polarized omnidirectional antenna (isotropic radiator) has, by definition, a gain of unity (0db). A bi-polarized antenna with the same average must have a gain of 1/2 (-3 db). Such an antenna has an effective aperture ($A_{eff} = G \lambda^2/4\pi$) varying from 143 cm^2 to 21 cm^2 over the 500 to 1300 mcs frequency band. When exposed to the 2.5×10^{-10} watts per cm^2 field, signals ($P_d \times A_{eff}$) from -44.5 dbm to -52.8 dbm would be received.

Consider next what would happen if six antennas were used, with the detected outputs being added to obtain the full pattern coverage desired. If six antennas with idealized, straight-sided, flat-top patterns were to provide the full spherical coverage, each would have a beam area equal to one-sixth the surface area of a unit sphere, and have a gain six times that of the equivalent omnidirectional radiator. Thus, for circular polarization, each of the six idealized antennas would have an absolute gain of 3(4.8db). The signal received by such an antenna in the 2.5×10^{-10} watts per cm^2 field would be 6 times (7.8 db) greater than the previously computed -44.5 to -52.8 dbm figures.

The apparent factor of six improvement cannot actually be realized since the detected outputs of the six antennas cannot be added without effecting a change in the receiver noise level. In a linear adding circuit, the detected signals in the separate lines will add directly but the noise, being noncoherent, will have a value equivalent to the square root of the squares of the separate

HANDLE VIA
BYEMAN ~~TALENT-KEYHOLE-COMINT~~
CONTROL SYSTEMS JOINTLY

~~TOP SECRET~~

[redacted]

noise inputs, considering six antennas, the factor of six increase in signal is reduced by a factor of $\sqrt{6}$ increase in noise resulting in a net improvement in ~~signal to noise ratio of~~ [redacted] 2.45 or 3.9 db improvement as the net increase in received signal rather than considering both signal increase and the change in receiver noise level. Thus, the effective signal level received with the system in the reference field will vary from -40.6 dbm to -46.9 over the 500 to 1300 mcs frequency range. These sensitivities values are attainable and will be considered in the filter-detector section as well as the overall system performance section of this proposal. However, there are many sources of signal loss which have not as yet been considered. Idealized antenna pattern coverage has been assumed with no variation in gain due to either space orientation or polarization variation. Any deviation from the idealized pattern will result in less antenna gain in same section. Losses occur in the filter pass band but these losses are accounted for when the sensitivity of the filter-detector unit is considered. Attenuation losses are expected in the r-f cables, as well as losses due to impedance mismatches between components. Some sensitivity variation is also to be expected in the crystal response over the frequency band and in the variation in characteristics from crystal to crystal and also from a single crystal as the temperature is varied.

The characteristics of the separate components are discussed in the following sections.

2.1 Antennas

In the preceding paragraphs it was shown that an idealized antenna system to provide omnidirectional bi-polarized pattern coverage would have an element gain equal to one-half the number of elements used, that is, a power gain of 3 (4.8 db) if six antennas were used. In a lossless system, increases or decreases in gain in one section or for one polarization must be accompanied by a related decrease or increase in another sector. Additional gain cannot be designed into the antenna system. The design problem is to obtain overall uniformity of pattern, together with low VSWR and losses.

The antenna system will consist of six quarter-wave length monopole antennas equally spaced around a sphere to obtain omnidirectional pattern coverage. The monopole will protrude approximately 4.5" and leave a diameter of approximately 0.5". Each antenna is followed by a filter and crystal detector. The large diameter is necessary to obtain an impedance match over a frequency band as wide as the 500 mcs of 1300 mcs range. The success of this type of system has been demonstrated by the antenna performance attained with the S-Band system. However, some slight degradation in pattern performance should be anticipated due to the effective decrease in the sphere size. In the S-Band case, the sphere was a many wavelength ground plane to each monopole while in the L-Band the 20 inch sphere represents a ground plane that is less than one wavelength large at 500 MCS.

As demonstrated by the S-Band system, the monopole system is ideal for mounting in the sphere to give bi-polarized omnidirectional coverage. The gain of such a system is 3/1 (4.8). As a component item the monopole is very lightweight (less than two ounces), rugged, efficient and of the very simplest construction.

VIA BYEMAN-TALENT-KEY CONTROL SYSTEMS JOINTLY

Of cours [redacted] e are other antenna systems that could be considered but none offer the me [redacted] the monopole antenna system.

TOP

2.2 Filter and Detector Mounts

The des[redacted] the 500 mcs to 1300 mcs bandpass filter and detector is a major problem area of this system. The paperwork design of such a bandpass filter with extremely steep cutoff slopes (50 db @ 10% below passband cutoff) has been completed and there remains only the fabrication and empirical design to achieve the desired filter performance. The general design of a 500-1300 mcs bandpass filter of the type that would be used is discussed in the following paragraphs.

The filter requirements are as follows:

Type - Band Pass

$f_1 = 500$ MC $\quad f_2 = 1300$ MC

Insertion Loss at 450 MC $\geq$ 50 db.

In addition, the pass band insertion loss should be relatively low and the upper stop band should extend to at least 11 KMC. In order to obtain maximum sensitivity, it is desirable to package the crystal (video detector) with the filter and if possible, include the crystal parameters.

A band-pass filter circuit which is capable of wide bandwidth and steep cut-off slopes is shown in Figure 1. The lumped element equivalent circuit of Figure 1 has 7 resonant sections, 4 series resonant circuits and 3 shunt parallel-resonant circuits. Modern network theory has shown that in order to achieve the maximum cut-off slope for any given ripple, or loss tolerance in the pass band, it is necessary to use the Tchebyshev type response,

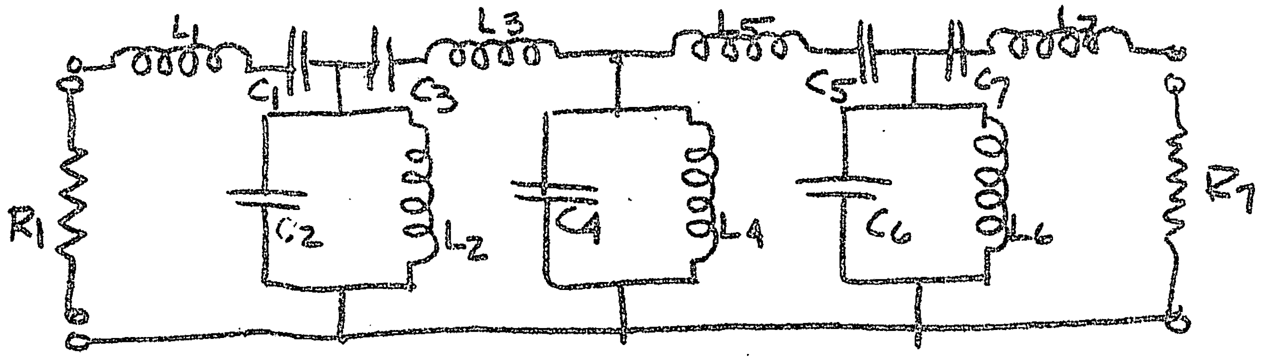

Figure 1

$$(V_p/V)^2 = 1 + \left[(V_p/V_v)^2 - 1\right] \left[T_n\ (X/X_v)\right]^2,$$

Where $T_n\ (X/X_v) = \cosh\ (n \cosh^{-1} X/X_v)$, and

V_p = peak output voltage in pass band
V = output voltage at point X
V_v = valley [redacted] voltage in pass band
n = number s, or for band-pass filters n = total number of res in the filter
$X = (f_2 - f_1)/f_o = BW/f_o$ (for symmetrical band-pass filters)
X_v = value of X at point on response skirt where attenuation equals valley attenuation.

HANDLE VIA
BYEMAN ~~TALENT-KEYHOLE~~
CONTROL SYSTEMS JOINTLY

~~TOP~~

[redacted]

~~TOP SECRET~~

A plot of 10 log $(V_p/V)^2$ versus (X/X_v) will give a filter response curve, in db, for any given value of (V_p/V_v), or pass band ripple, and for any given number of resonators, n. In order to determine the minimum number of resonators required for this application it is necessary to evaluate the Tchebyshev polynomial for various values of n. The Tchebyshev polynomial need be evaluated only for the particular value of (X/X_v) of interest in this particular case since the general filter response vurve is well known. Since 50 db attenuation is required at 450 MC, the required 50 db down bandwidth will be 1430 - 450 = 980 MC. (Since the filter response is considered symmetrical and the low-end response is down 50 db at 10% below f_1, then the high end response must be down 50 db at 10% above f_2, or in this case, 1430 MC.) The value of X is then 980/806 = 1.215, where $f_0 = \sqrt{(500)(1300)} = 806$ MC. If the attenuation at f_1 and f_2 is made equal to the valley attenuation (instead of the conventional value of 3 db), $X_v = BW/f_0 = (f_2 - f_1)/f_0 = 800/806 = .993$ and the value of (X/X_v) of interest in this particular case is about $X/X_v = 1.22$.

Calculations show that ten resonators are not quite sufficient to provide the required cutoff slope but that eleven resonators are the minimum number which can be used to satisfy the filter requirements. The lumped element equivalent circuit for n = 11 is shown in Figure 2, where it is noted that the circuit is symmetrical, which in some cases is an advantage in construction or "physical realization" considerations.

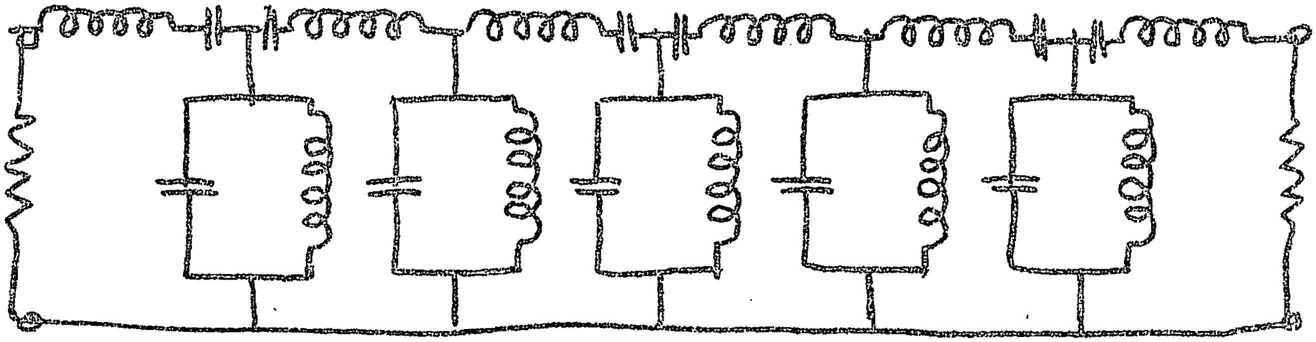

Figure 2

It is next necessary to calculate the ladder form of normalized coefficients of coupling (k) and normalized Q's (= q), which can then be related to the inductance, capacitance, and resistance values for the filter type shown in Figure 2. To do this, it will be assumed that equal resistive terminations will be used, i.e. the generator and load are resistive and equal. The filter circuit parameters may be adjusted later to incorporate the crystal (video detector) as a load. This must be done by empirically determining the equivalent circuit parameters of the crystal over this frequency range and adjusting the terminating elements of the filter to make the crystal a part of the last filter element. It is understood, of course, that complete "adjustment" may not be possible and also that it may be necessary to "effectively" add another resonator (which, in this case would b unt parallel-resonant circuit) in order to effect the most complete adjust[redacted] Further for the purpose of reducing the complexity of the calculations, i be assumed that a lossless transmission line will be used, i.e. the circuit elements are assumed to have infinite Q. There does exist, of course, a minimum Q for the circuit elements, below which the filter cannot be realized.

~~TOP SECRET~~

Normally a Q of 10 times the minimum Q is considered as infinite Q, or as representative of lossless circuit elements. (A method for adjusting the normalized k and q valu[redacted]r finite element Q's between Q min. and 10 Q min. is given in refere p. 222)

The relationships for determining the normalized coefficients of coupling (=k) and normalized Q's (=q) are:

$$\frac{Q_{1,n}}{f_o/BW_v} = q_{1,n_v}\ db = (2 \sin \Theta)/S_n$$

$$\left[\frac{K_{r,(r+1)}}{BW_v/f_o}\right]^2 = \left[k_{r,(r+1)_v}\ db\right]^2 = \frac{S_n 2 + \sin^2 2r\Theta}{4\left[\sin (2r-1)\Theta\right] \sin (2r+1)\Theta}$$

$$\text{where } \Theta = 90^{\circ}/n \text{ and } Sn = \sinh\left\{(1/n) \sinh^{-1}\left[(V_p/V_v)^2 - 1\right]^{\frac{1}{2}}\right\}$$

These expressions have been evaluated for the k and q values of an eleven pole no-zero filter. Using the k and q values calculated, the values of L and C have been computed.

Next it is necessary to physically realize the circuit element (L & C) values, in the form of the equivalent circuit of Figure 2, in a microwave transmission line having distributed elements. As will be shown, strip transmission line techniques land themselves readily to this type of filter design. The strip-line to be used is of the "sandwich" type construction and consists of a thin narrow strip of copper supported between two thin parallel metal sheets, on ground planes, as is shown in Figure 2. The most widely used material for strip transmission lines, [redacted] of its relatively low loss tangent, is teflon impregnated fiberglass s copper clad on either one or both sides. Most of the filters designed in strip-line by ITT Labs use 1/8 inch ground plane spacing, or two 1/16 inch double copper-clad teflon impregnated fiberglass laminates. The characteristic impedance of strip-line, for a given dielectric material, ground plane spacing, and copper thickness, is determined by the width, w, of the center

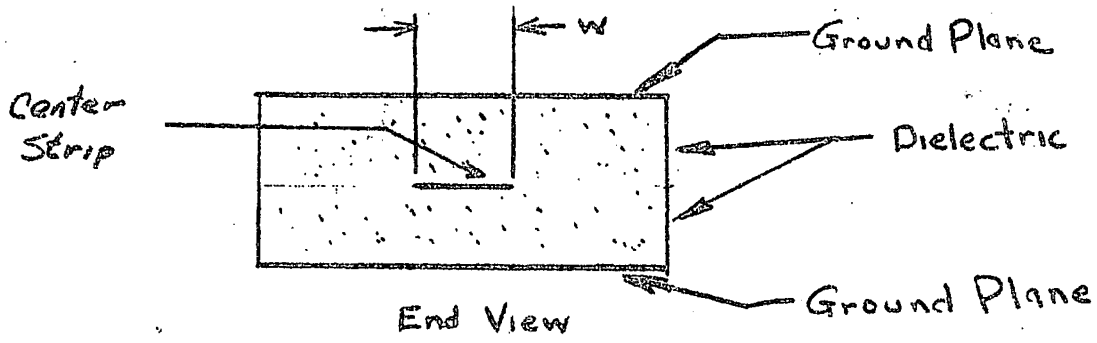

Figure 3

strip. Series induct[redacted] be simulated by a length of high impedance line, while shunt capacity [redacted]alized by a length of low impedance line. (Note the similarity to coaxial transmission line). A high impedance is obtained by use of a narrow center strip, while a low impedance line is obtained by a wide center strip. Shunt parallel-resonant circuits may be simulated by a short-circuited stub, whose length is $\lambda_0/4$. The characteristic impedance of the short-circuited stub may be adjusted to give equivalence between its "reactance-curve" and the "reactance-curve" of the actual circuit in the vicinity of the origin. Very small series capacities may be simulated by using gaps in the center conductor. However, it is usually necessary to use a "double-etching center-strip overlapping" technique to obtain practical values of series capacity. This technique has been used quite successfully by ITT Labs on several band-pass filters. The "overlapping" technique" is accomplished by etching alternate sections of the filter circuit on opposite laminates such that overlapping of the center strips occur when the two boards are assembled. The most commonly used dielectrics separating the overlapping center strips are teflon tape and Mylar film. Mylar is available in thicknesses ranging from 1/4 mil to several mils so that a wide range of series capacities may be realized for a limited range of overlapping. It is usually desirable to keep the length of overlap small compared to a wavelength so when large series capacities are required, it is necessary to use wide center strips in the region of the overlap, and thin dielectric separation. Widening of the center strip lowers its characteristic impedance and introduces shunt capacity into the equivalent circuit. It is sometimes difficult, therefore, to simulate large series capacities without introducing shunt capacity, which is often undesirable.

The resulting strip-line filter will be about 3 to 4 inches in width and about 12 to 13 inches in length, including input transitions and integral crystal video detector. Since the filter thickness is only slightly more than 1/8", three filters could be stacked and thereby occup a volume of only approximately 3" x 13" x ½". It is possible to curve the center strip such that the final form factor can be a circular disk, or the center strip can be folded back on itself to decrease the length at the expense of an increase in width of the filter.

It may be necessary to add a few low-pass filter sections to the band-pass filter in order to eliminate spurious pass-bands below 11 KMC. These sections would be relatively small, since the cut-off frequency of the added low-pass sections would be on the order of several kilomegacycles.

All of the above filter discussion is on the basis that it is necessary to achieve the steep cutoff slopes. (50 db @ 10% above and below passband). If this requirement were eased, it would make the filter shorter than the 12 or 13 inch length by reducing the number of filter sections required.

2.3 Amplifier

It is not felt that it is necessary to give a lengthy discussion on the amplifier as it would be the same transistorized linear video amplifier that was used with [redacted]nd receiver.

[redacted]

The amplifying system consists of two assemblies, a four cascaded transistor feedback pair amplifier and a crystal bias network.

The maximum gain of the four pair amplifier is approximately 2000. A resistor in the second pair feedback provides a gain adjustment of full gain for a certain value resistor and 23 db below full gain for an open circuit. Any gain between these values may be obtained with a suitable resistor.

The bias network provides a means of paralleling the signal outputs of crystal detectors while providing individual dc bias to the crystals.

The total power required to operate the amplifier is 60 milliwatts (12 volts dc).

2.4 System Performance

The overall system sensitivity can be determined from the characteristics of the separate components. In general, the attainable receiver tangential sensitivity in terms of r-f power level into the detector mount is estimated to be -56 dbm to -60 dbm. (This is the equivalent sensitivity of a single input receiver with one detector and no adding.) The power level at the terminals of a single antenna for a system of six antennas providing bi-polarized omnidirectionality would vary from -44.5 to -52.8 dbm over the 500 to 1300 MCS frequency band. The expected signal losses and signal variations to the input of the filter-detector units will consist of:

Antenna pattern and polarization variation	3 db
Cable attenuation	1 db
Miscellaneous mismatch losses	1 db
Total losses before input to filter-detector unit	5 db

As previously discussed, the signal level at the input of the filter-detector mount would be approximately -49.5 to -57.8 dbm. The full antenna gain cannot be realized in increased system sensitivity since the process of signal addition also involves a change in the noise level. The net increase in signal-to-noise ratio is equal to the square root of the number of elements combined (2.45 for six antennas). The factor of 2.45 (3.9 db) combined with the above sensitivity factor results in an equivalent input signal level to the filter from -45.6 to -53.9 dbm over the frequency range. The -45.6 to -53.9 dbm figures must be sensitivity of the combined filter-detector assembly in order to achieve a tangential sensitivity of 2.5×10^{-10} watts /cm^2. This means that if the filter has a 3 db pass band insertion loss the detector must have a sensitivity of -48.6 to -56.9 dbm over the frequency range. These sensitivity values are within reason by placing special emphasis on matching the detector at the higher frequencies in band to achieve the -56.9 dbm sensitivity. On the basis of the above discussions, it is anticipated that the entire receiving system would have a tangential sensitivity of 2.5×10^{-10} watts/cm^2.

~~TOP~~

HANDLE VIA
BYEMAN-~~TALENT-KEYHOLE~~
CONTROL SYSTEMS JOINTLY

[redacted]

Page Denied