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Inventor: Shane J. Strutz

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PATENT APPLICATION/TECHNICAL DIGEST PUBLICATION RELEASE REQUEST

FROM: Associate Counsel (Patents) (1008.2)

TO: Associate Counsel (Patents) (1008.2)

Via: (1) Shane Strutz (Code 5650)
(2) Division Superintendent (Code 5600)
(3) Head, Classification Management & Control (Code 1221)

SUBJ: Patent Application/Technical Digest entitled: "**OPTICAL IMAGE REJECT DOWN CONVERTER**" Request for release for publication.

REF: (a) NRL Instruction 5510.40C
(b) Chapter 6, ONRINST 5870.1C

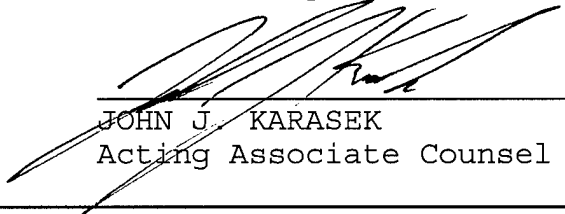
ENCL: (1) Copy of Patent Application/Technical Digest

1. In accordance with the provision of references (a) and (b), it is hereby requested that the subject Patent Application/Technical Digest be released for publication.

2. It is intended to offer this Patent Application/Technical Digest to the National Technical Information Service, for publication.

3. This request is in connection with Navy Case No. 82,545

9/26/00
(date)



JOHN J. KARASEK
Acting Associate Counsel (Patents)

FIRST ENDORSEMENT

Date:

FROM: Shane Strutz (Code 5650)

TO: Division Superintendent (Code 5600)

1. It is the opinion of the Inventor(s) that the subject Patent Application/Technical Digest ~~(is)~~ (is not) classified and there is no objection to public release.

 9-22-2000

Inventor's Signature

SECOND ENDORSEMENT

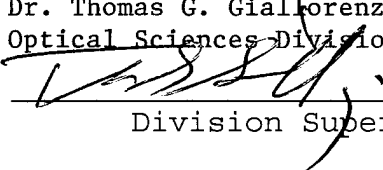
Date: 22 SEP 2000

FROM: Division Superintendent (Code 5600)

TO: Classification Management & Control (Code 1221)

1. Release of Patent Application/Technical Digest (is) (~~is not~~) approved.
2. To the best knowledge of this Division, the subject matter of this Patent Application/Technical Digest (~~has~~) (has not) been classified.
3. This recommendation takes into account military security, sponsor requirements and other administration considerations and there in no objection to public release.

Dr. Thomas G. Giallorenzi, Superintendent
Optical Sciences Division, Code 5600



Division Superintendent


THIRD ENDORSEMENT

Date:

FROM: Head, Classification & Control (Code 1221)

TO: Associate Counsel (Patents) (1008.2)

1. This Patent Application/Technical Digest is authorized for public release.



Head, Classification, Management & Control

5

OPTICAL IMAGE REJECT DOWN CONVERTER

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BACKGROUND OF THE INVENTION

Field of the Invention

This invention pertains generally to an optical downconverter and more specifically to an invention for improving the image rejection capability of image rejection downconverters.

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Description of the Related Art

There are two primary types of image rejection systems that provide significant frequency translation; those which use a digital phase modulator to produce a serrodyne phase modulated waveform and those which split a received signal into two parts and then recombine them in a way which eliminates the unwanted image and carrier frequencies.

20

Optical image rejection mixers that utilize the serrodyne method of frequency translation apply a phase modulated sawtooth waveform to the optical signal, thereby causing the frequencies to shift. The achievable image rejection is limited by the number of discrete bits that can be implemented by the digital phase modulator when approximating the sawtooth waveform.

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This limits the image rejection to approximately 25 dB.

In the case of microwave image rejection mixers, the achievable image rejection is limited by the need for near perfect amplitude and phase control. As shown in **Figure 1**, a

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5 received radio frequency (RF) signal **12** is first divided into, two RF signals **16** and **18** in an in-phase power divider **14** mixed with an electromagnetic signal **22** from a local oscillator, (commonly referred to as LO IN) which is split into two signals **24** and **26** in a first 3 dB 90° hybrid combiner **28**. The mixers **32** and **34** mix the pair of signals from the local oscillator **26** and **28** with the pair of input RF signals **16** and **18** to produce a pair of respective RF signals **36** and **38** having a 90° phase shift between the two component signals **36** and **38**, which are recombined in a second 3 dB 90° hybrid circuit **42** to produce an output intermediate frequency (IF) **44** for use by other electronic components (not shown). Exact amplitude and phase matching with broad band signals is nearly impossible with strictly microwave components since the frequency response of each of the components varies. A typical device, with a 3° phase error and a 0.25 dB amplitude imbalance upon recombination, is limited to about 30 dB of image and carrier rejection. Further details on serrodyne frequency shifting is found in Johnson et al.,
15 **SERRODYNE OPTICAL FREQUENCY TRANSLATION WITH HIGH SIDEBAND SUPPRESSION**, J. of Lightwave Tech.; Vol. 6, pg. 109, 1988.

20 An optical image rejection downconverter with >60 dB of image rejection is a recently developed device that utilizes an electronic mixer to upconvert signals into the passband of a bandpass filter followed by optical downconversion of the filtered signals into the desired output band. This system developed by Ward et al. for which patent protection is being sought in the Navy Case No. 79,800, U.S. Patent Application Serial Number (not yet assigned) filed on July 17, 2000, entitled **IMAGE REJECTING MICROWAVE PHOTONIC DOWNCONVERTER** is

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5 an improvement over the previous presented optical and electronic mixers. The system exhibits more than 60 dB of image rejection; however, it is limited by the production of unwanted harmonics by the upconverting mixer. The key to eliminating the spurious signals is to change which sideband is filtered. In Ward et al. the system is designed to operate with the local oscillator (LO1) at a frequency below the passband of the band pass filter (BPF), causing the
10 negative (lower sideband) frequencies of the received RF signal to be shifted into the bandpass of the BPF. With this technique, unwanted frequencies are converted into the passband of the bandpass filter and as a result appear at the output of the system. These unwanted frequencies produce spurious signals in the system output which are only 25 dB below the desired signal power, severely limiting the sensitivity of the system.

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SUMMARY OF THE INVENTION

A object of the invention is a device to increase the amount of image rejection while decreasing the power in harmonic spurious radiations to approximately 60 dB below the desired signal power in an image rejection device.

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Another object of this invention is to provide a device for upconverting broadband electrical signals, filtering out image frequencies in the electrical domain and then downconverting the desired frequency using optical techniques.

Another object of this invention is to obtain a frequency shifted microwave signal utilizing electro-optic modulators and bandpass electronic filters.

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Another object of this invention is to provide an analog device that does not rely upon

5 phase or amplitude matching to achieve image rejection.

These and other objects are accomplished by a remotable, ultrawide band optical image rejection downconverter using sub-carrier modulation techniques without concern for image frequency interferences in the shifted signal, thereby allowing telecommunications systems to downconvert densely multiplexed communications channels into a low frequency band where
10 conventional electronics can perform signal-processing functions. Further, this invention has the image rejection (>120 dB) to provide unambiguous signals for direction finding applications and exhibits an efficient image that permits multi-octave microwave frequency reception and compression. This invention is intrinsically remoteable, and due to the various optical and electrical components proves to be very useful and practical in numerous fiber optic and antenna
15 systems.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a microwave image rejection mixer of the prior art.

Figure 2a shows a mixing that occurs between the radio frequency signal and the injected
20 signal from the first local oscillator (LO1).

Figure 2b shows a superposition of the resulting mixer IF output.

Figure 2c shows a filtered output of the upconverted RF upon leaving the bandpass filter downconverted to the desired IF frequency range using a fixed second local oscillator (LO2) carrier.

5 **Figure 3** shows a schematic of an optical image rejection downconverter

Figure 4 shows a plot of the conversion loss of an optical image rejection downconverter.

Figure 5 shows an all-microwave image rejection downconverter.

Figure 6 shows a wideband image rejection downconverter with an optical upconverting
link.

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DESCRIPTION OF THE PREFERRED EMBODIMENT

 This invention is a remotable, ultrawide band optical image rejection downconverter
image rejection to greater than 120 dB, and rejection of harmonic spurious conditions to more
than 60 dB below the desired signal power. The general operational principles of the invention
15 are shown in **Figures 2a, 2b** and **2c**. **Figures 2a, 2b** and **2c** depict a graphical representation of
the traditional and image rejecting downconverter input signals. **Figure 2a** shows the mixing
that occurs between the radio frequency signal and the injected signal from the first local
oscillator (LO1). **Figure 2b** shows the superposition of the resulting mixer IF output. **Figure 2c**
shows the filtered output of the upconverted RF upon leaving the bandpass filter downconverted
20 to the desired IF frequency range using a fixed second local oscillator (LO2) carrier.

 In this embodiment, any spurious signal problem is alleviated by choosing LO1
frequencies above the passband of the BPF, causing the positive frequencies (upper sideband) to
be shifted into the passband of the BPF. Using high frequency LO1 values removes the problem
of harmonic upconversion of LO1, and the conversion of spurious signals. The increased image

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5 rejection of this embodiment is a distinct advantage over the typical ferrodyne and electronic mixers; and the reduction in the spurious signal power is a distinct advantage over the systems of the prior art.

The remotable, ultrawide band image rejection mixer maps signals into an arbitrary intermediate frequency band, thereby allowing telecommunications systems to downconvert
10 densely multiplexed ultrawide bandwidth channels into low frequency bands where conventional electronics can perform signal-processing functions. Further, this invention has the image rejection (>120 dB) to provide unambiguous signals for direction finding applications and exhibits an efficient image that permits multi-octave microwave frequency reception and compression. In addition, this invention is intrinsically remoteable, and due to the various
15 optical and electrical components proves to be very useful and practical in numerous fiber optic and antenna systems.

Referring to **Figure 2a**, radio frequency (RF) signals, f_{RF} , received by the system are first upconverted with a first local oscillator (LO1) ($f_{UP} = f_{LO1} - f_{RF}$). As a result, a portion of the positive frequency components (upper sideband) is shifted into the passband of a bandpass filter
20 (BPF), **Figure 2b**. The BPF attenuates the unwanted upper sideband frequencies, the image band, and original signals, leaving only the desired shifted frequencies. Next the output of the BPF is mixed with a second local oscillator (LO2) to downconvert the filtered signals into a desired output band, representing an intermediate frequency (IF) usable by conventional electronics. Unlike the cited prior art, the LO1 in this invention is at a higher frequency than the

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5 passband of the BPF and operates by shifting the positive frequency components into the passband. This eliminates the conversion of unwanted signals into the passband of the BPF and the subsequent production of spurious signals within the output of the system, as shown in **Figure 2c**. This system provides a significant improvement over image rejection downconverters of the prior art.

10 The optical image rejection downconverter **10**, as shown in **Figure 3**, consists of an upconverting and a downconverting photonic RF/link, **52** and **54**, respectively. The upconverting link **52** is further comprised of a first laser light source **56**, providing an optical carrier **58** at a wavelength λ_1 , which is modulated by a sinusoidal electrical signal **62** generated by a first local oscillator (LO1) **64**, in a first optical modulator **66**, such as a Mach-Zehnder optical modulator or
15 similar device, to produce a first modulated optical carrier **68** which is applied to a first high speed photodetector (PD1) **72**, where the optical carrier **68** is converted to an electrical signal **74** by a photodetector which is biased in the bias tee **82**. The electrical signal is amplified by a first amplifier (A1) **76** and drives an upconverting mixer **78**.

20 The electronic mixer **78**, the amplified electrical signal **82** is mixed with an analog ultra-broadband radio frequency (RF) signal **84** from a remote antenna receive array (not shown) to produce an upshifted frequency band signal **86**. The mixer **78** acts to shift the entire RF band to a higher frequency band equal to the original RF frequency plus the frequency of the LO1 **64**.

The optical fiber conducting the optical carrier **58** from the first laser polarization maintaining fiber and the optical fiber conducting the modulated optical carrier **68** from the first

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5 optical modulator **66** to the first photodetector (PD1) **72** may be of any type.

The downconverting link **54** is comprised of a second optical light source (L2) **102**, centered at a wavelength, λ_2 , which provides a second optical carrier **104** which is modulated by a sinusoidal electrical signal **106**, generated by a second local oscillator (LO2) **108**, in a second optical modulator **112**, which is preferably a Mach-Zehnder optical modulator, however any
10 suitable optical modulator well known to those skilled in the art may be used, to produce a second electro-optically modulated carrier **114**. The second electro-optically modulated carrier **114** is passed through a beam splitter **116** where it is passed through a double-pass erbium doped fiber amplifier (EDFA) **118** and reflected in a Faraday Mirror **116** and again passed through the beam splitter **116** and applied to a third optical modulator **122** producing a delayed second
15 electro-optically modulated carrier **119**.

In the downconverting link **54**, the up-shifted frequency band signal **86** is applied to an electronic band pass filter (BPF) **88**, preferably having a bandpass of 9 - 10 GHz with -80 dB attenuation, which attenuates all unwanted frequencies, including the original RF band and other converted terms, frequencies outside the up-converted passband, before amplification by a
20 plurality of electronic amplifiers **92** and **94** (however, one amplifier may be sufficient) to produce an amplified filtered upshifted frequency band electrical signal **98**. The amplified filtered upshifted frequency band signal **98** is applied to the third optical modulator **122** to modulate the delayed second electro-optically modulated carrier **119**, producing a downconverted optical signal **124** of 1 -2 GHz. The downconverted optical signal passes through an optical fiber to a

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5 second photodetector (PD2) **126** producing an intermediate frequency electrical signal **128**
transmitted to the electrical outport of the system for application to user electronics.

The information shown in **Figure 4** is the conversion loss of the system plotted for LO1
64 frequencies of 10.8, 11.8, 12.8, 13.8, 14.8, 15.8, 16.8, and 17.8 GHz and an LO2 **108**
frequency of 8 GHz. The conversion loss is between 3 and 10 dB across the 0.8 -8.8 GHz RF
10 receive band of the system.

The optical light sources (lasers) L1 and L2 **56** and **102**, respectively, are of relatively low
relative intensity noise level and, preferably, are shot noise limited. A semiconductor distributed-
feedback (DFB) laser has been found to be adequate for the system, however, any laser meeting
the requirements may be used. Also, a single mode laser is preferred, however, a multimode
15 laser may be utilized. The only restriction is that the laser be a low noise laser.

Optical fibers connecting the first optical modulator **68** with the first photodetector (PD1)
72 and the second optical modulator **112**, and third optical modulator **122** to the second
photodetector (PD2) **126** are single mode fibers. The optical fiber between the lasers L1 and L2,
56 and **116**, respectively, and the optical modulators **66** and **104** is a polarization preserving fiber
20 because the optical modulators **66**, **106** and **122** are polarization sensitive. Though it is realized
that the advent of polarization insensitive modulators would allow the use of single or multimode
fiber.

The first and second modulated optical carries **68** and **114**, respectively, may be
transmitted independently by two polarization-maintaining (PM) optical fibers of arbitrary length

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5 because the local oscillators **64** and **108** are at different frequencies. In the case of thermal fluctuations, or other irregularities, the phase does not have to be kept constant between the outputs **68** and **114** of the modulators **66** and **112** because of the lack of any phase relationship between the local oscillators LO1 and LO2 **64** and **108**, respectively.

10 LO1 **64** and LO2 **112** have low phase noise characteristics. In this application, any local oscillator of decent quality may be used, such as a cavity oscillator. However, it is noted that LO1 **64** is tunable and acts to translate a desired portion of the received RF frequency band through the bandpass filter **88**. LO2 **112** need not be tunable. The purpose of LO1 **64** being tunable is that it shifts the RF input frequency **62** into the pass band of the bandpass filter **88**. The LO1 **64** frequency is determined by the RF input signal **62** frequency range, DC to 18 GHz,
15 at the input, and on the frequency range of the bandpass filter **88**. In order to avoid overlap between the original RF input band **62** and the filtered passband signal **96** at the output of the electronic mixer **78** (similar to the unisolated RF indicated in **Figure 2b**), the filter **88** is chosen so that the lower limit of the filter passband is a few GHz higher than the maximum RF input **84** frequency. In addition, LO isolation becomes a concern as the minimum RF input **78** frequency
20 approaches DC because the LO frequency required to upconvert will approach the lower limit of the filter passband. As the RF input **84** of interest increases from low frequencies to high frequencies, the frequency of LO1 **64** is decreased from its maximum by the same amount so that the corresponding upconvert frequency **86** lies within the filter **88** passband. The frequency of LO2 **112** is constant because the desired portion of the upconverted mixer output **86** is always

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5 within the fixed filter **88** passband.

LO1 **64**, as previously stated, is tunable and acts to translate, in the frequency domain, a desired portion of the received Rf frequency **84** band through the bandpass filter **88**. In this way, different regions of the RF band **84** can be transmitted through the filter **88** and downconverted to the intermediate frequency (IF) band **128**. Because of the excellent RF to IF isolation of the system **10** due to a 50 to 80 dB filter **88** rejection, the IF band **128** is less than the LO2 **112** frequency. The width of the IF band **128** is determined by the width of the bandpass filter **88**, Image and fundamental carrier rejection is achieved because those frequency bands are attenuated by the bandpass filter **88**, and therefore are not downconverted to the IF band **128**.

15 The only specific requirement for the photodetectors PD1 and PD2 **72** and **126**, respectively, is that they have enough bandwidth to cover the IF frequency range of the device.

The mixer **78** is a triple balance mixer so as to provide ultra-wideband capability; it must have a large bandwidth signal capability at the input and convert the RF signal **84** to a broadband signal **86** at the output so as to provide a useable signal that is easily processed by the present day electronics as long as it covers the input frequency range desired. This requirement is well known to those skilled in the art. Therefore, if only a few GHz are desired to be studied, then a double-balanced or a single-balanced mixer may be used.

20 The amplifiers A1 and A2 **92** and **94**, respectively, are typically narrowband amplifiers. A1 and A2 **92** and **94**, respectively, have to be as wide as the filter **88** bandpass. A single amplifier may be substituted for A1 and A2, **92** and **94** respectively.

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5 Typically, the bandpass filter **88** is a cavity filter with good rejection through the RF frequency **84** range, low loss within the bandpass frequency range and an attenuation of from 60 to 80 dB. Therefore, a typical cavity filter with a DC to 18 GHz range is suitable for the bandpass filter **88**.

10 It will be noticed that any image signals that would be present in the output would be the result of downconversion between LO2 **108** at 8 GHz and input RF frequencies that are converted (with LO1 **64**) into the 6 - 7 GHz band by the upconverting link. However, the 6 - 7 GHz signals are attenuated by the BPF **88**, and as a result, the system **10** exhibits excellent image rejection. The system described herein is ideal for remote application, since both the LO's **64** and **108** and the output **124** may be remotod.

15 In another preferred embodiment, a microwave only image rejection downconverter **20**, as shown in **Figure 5**, an RF signal **132** received by the system **20** is mixed with the signal from a first local oscillator (LO1) **136** in a first mixer **134** to produce frequencies at $f_{RF} \pm f_{LO1}$. As a result the positive frequency components (upper sideband) of the received signal **132** are shifted into the passband of the bandpass filter (BPF) **138**. The BPF **138** attenuates the unwanted upper sideband frequencies, the image band, and the original signals, leaving only the desired shifted frequencies **152**. These shifted frequencies **152** are then downconverted in a second mixer **146** to produce frequencies in the desired output band **148** ($f_F = f_{BPF} - f_{LO2}$).

20 In a third preferred embodiment **30**, as shown in **Figure 6**, the upconverting link **52**, shown in **Figure 3**, is replaced with an all optical upconverting link **154**. The downconversion

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5 link **54** of **Figure 3** remains essentially the same. The upconverting optical link **154** may utilize any type of scheme for mixing the RF and LO1 **162** and **178**, respectively. It may be done either with two series optical modulators **164** and **174**, as shown in **Figure 6**, or utilizing a single mixing modulator (not shown). After conversion of the mixed optical signal **182**, the signal **182** is converted into an electrical signal in a first biased **168** photodetector **166** and applied directly
10 to a bandpass filter **172**. The remainder of the circuit is as described above for the first preferred embodiment **20**.

The invention described herein provides image rejection of greater than 60 dB across more than 12 GHz, exceeding commercial devices by 25 to 45 dB. By virtue of low-loss optical fibers, this invention allows the lasers and local oscillators to be separated by several kilometers
15 from the remainder of the system. Thus this system may be implemented using a remote antenna site which is advantageous in many situations.

This invention allows the IF band to exist within the RF band, without interference, by using a two-step frequency shift technique and bandpass electronic filters. This differs from the traditional downconverting systems, where the IF bandwidth is limited to the region outside the
20 RF band due to RF-to-IF isolation considerations. For a .1 - 18 GHz system, and this would allow for only a DC - 100 MHz downconverted IF band. SEE, Linsay et al., PHOTONIC MIXERS FOR WIDEBAND RF RECEIVER APPLICATIONS, IEEE Trans. MTT; Vol. 43, No.9. pp.2311-2317, Sep. 1995; and Gopalakrisnam et al., A LOW LOSS DOWN CONVERTING FIBER OPTIC LINK , Vol. 43, No. 9, pp.2318 - 2323, Sep. 1995.

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5 With the microwave-photonic image rejecting downconverter, as shown in **Figure 5**, it is also possible to implement microwave sub-carrier modulation techniques without concern for image frequency interference in the shifted signal. **SEE**, Chao et al., **PHOTONIC MIXERS AND IMAGE-REJECTION MIXERS FOR SCM SYSTEMS**, IEEE Trans. MTT, Vol. 45, No. 8, pg. 1478, 1997. This allows telecommunications and CATV systems to downconvert densely
10 multiplexed communications channels into a low frequency band where conventional electronics can perform signal-processing functions.

 Another feature is highlighted by considering the photonic link noise figure (NF). Assuming a 50-ohm, shot noise limited system, the relationship between NF, photodetector current, and modulator half-wave voltage, V_{π} , is as described in Williams et al., **OPTICALLY**
15 **AMPLIFIED DOWNCONVERTING LINK WITH SHOT-NOISE-LIMITED PERFORMANCE**, IEEE Photonics Tech. Ltrts., Vol. 8, No. 1; pp. 148 - 150; Jan. 96. From this analysis a typical photodetector current and V_{π} of 10 mA and 10 V, respectively, combined with a 7dB conversion loss yields a noise figure well above a desired maximum NF of 15 dB. Therefore barring any advances in modulator V_{π} , phase matched preamplifiers are necessary at an antenna to
20 sufficiently decrease the noise figure of the system.

 Since the invention mixes RF signals to a relatively narrow passband, the phase matching requirements normally encountered are eliminated for coherent or incoherent applications. This invention makes phased matched direction finding arrays much more practical due to the reduced sensitivity requirements of the modulators **66**, **112** and **122**. In traditional phase sensitivity

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5 direction finding (DF) arrays which use optical modulators at the antenna site, the use of phase and amplitude matched preamplifiers over the entire RF bandwidth is necessary to achieve low noise figures. This invention relaxes those requirements since phase and amplitude matched amplifiers are only required over the desired filter passband, which in turn, is only as wide as the desired IF processing bandwidth. This is subtle, but very important advantage of this invention.

10 Referring again to **Figure 3**, an electro-optic modulator (e.g., Mach-Zehnder modulator) can perform the mixing function of the conventional microwave mixer **78**. Also, the two modulated optical carriers **68** and **114** may be combined onto a single PM optical fiber (assuming the optical carriers are of different wavelengths) using wavelength division multiplexing (WDM) techniques well known to those skilled in the art. The two modulated optical carriers **68** and **114**
15 are subsequently demultiplexed at the remote site onto separate PM optical fibers using the well known WDM techniques.

By virtue of the low-loss optical fibers, this invention allows the lasers and local oscillators to be separated by as much as 10 km, or more, from the remainder of the system. Thus, this system may be implemented using a more remote antenna site, which is advantageous
20 to many commercial communication and radar applications.

Further, this invention maintains a known phase relationship between the local oscillators **64** and **108** and the received RF signal **84**. This allows the image rejection system to be used as a direction finding system.

Although this invention has been described in relation to an exemplary embodiment

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5 thereof, it will be understood by those skilled in the art that still other variations and
modifications can be affected in the preferred embodiment without detracting from the scope and
spirit of the invention as described in the claims.

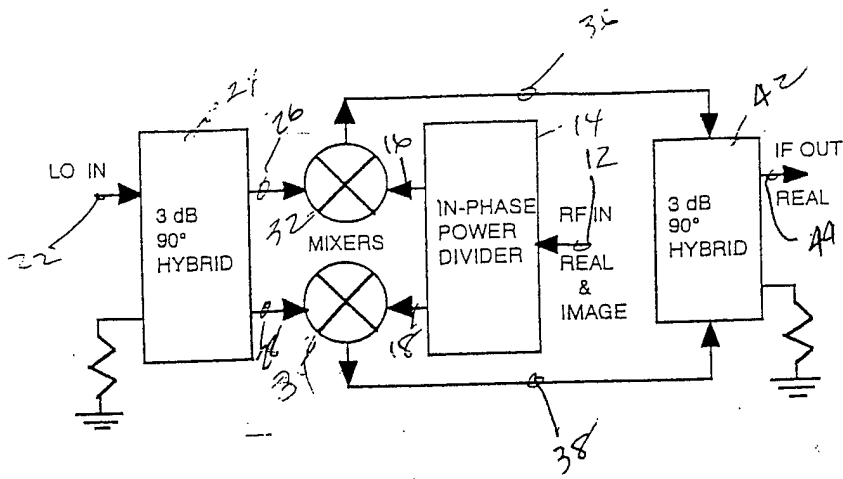


Figure 1
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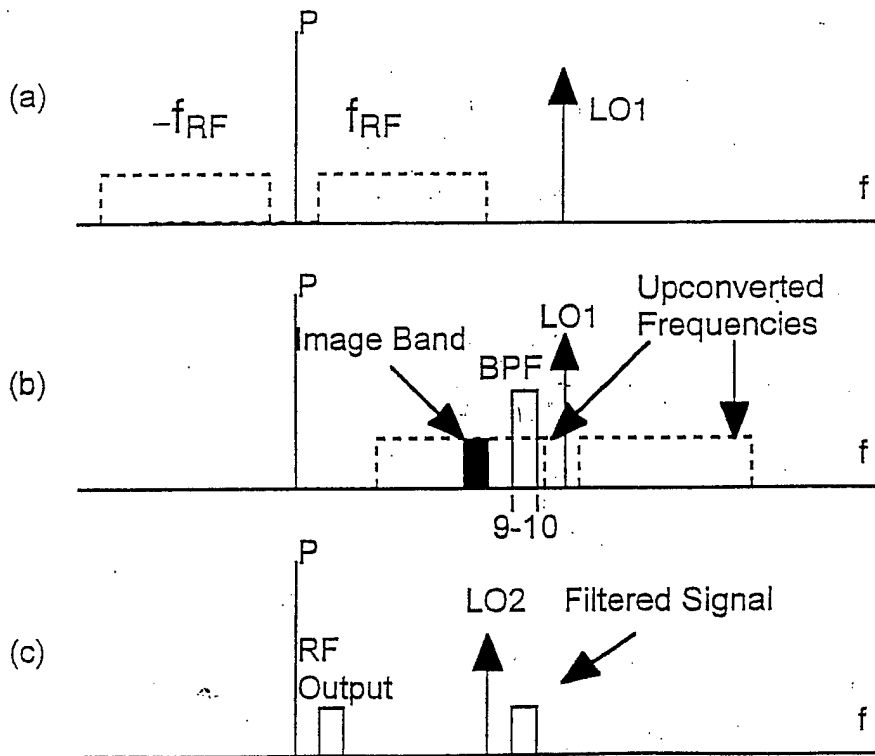


Figure 2

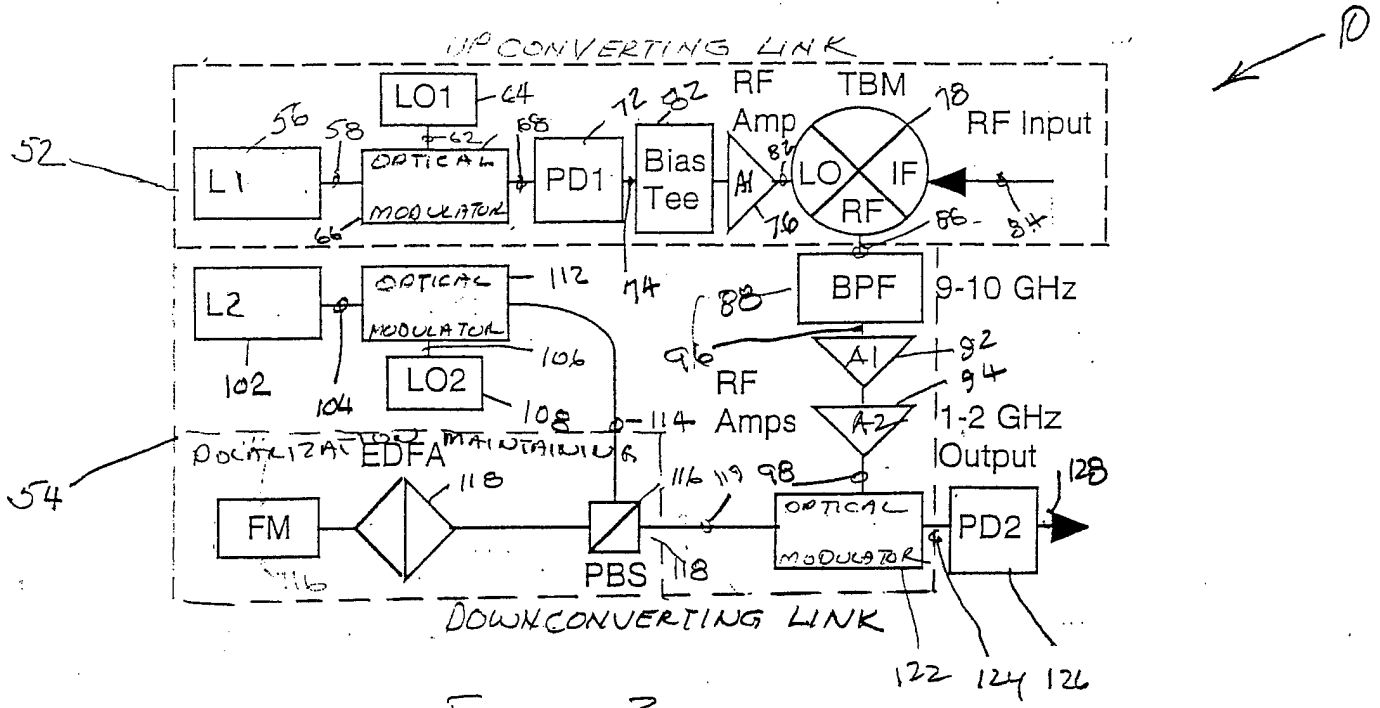


Figure 3

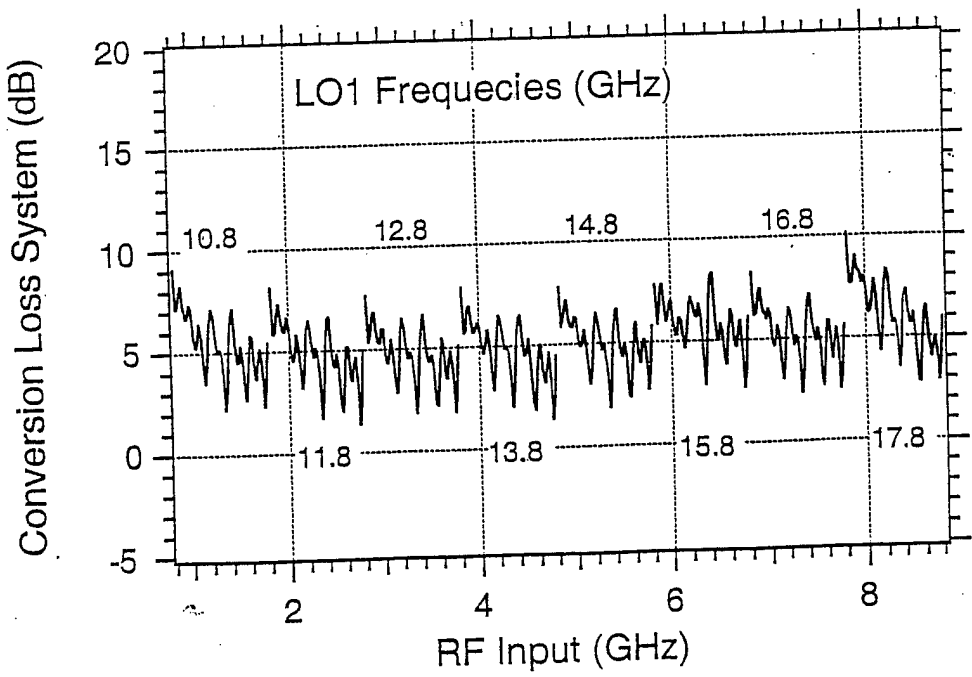
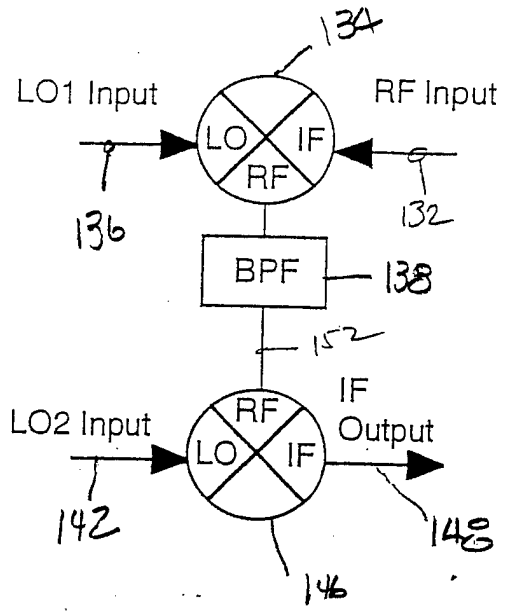
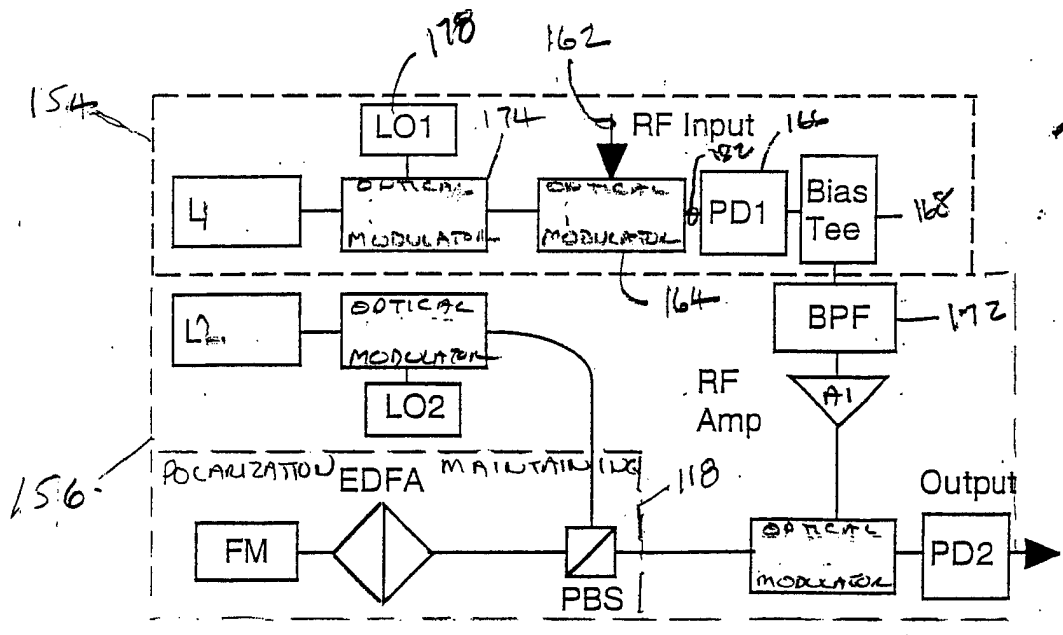


Figure 4



← 20

Figure 5



← 30

Figure 6